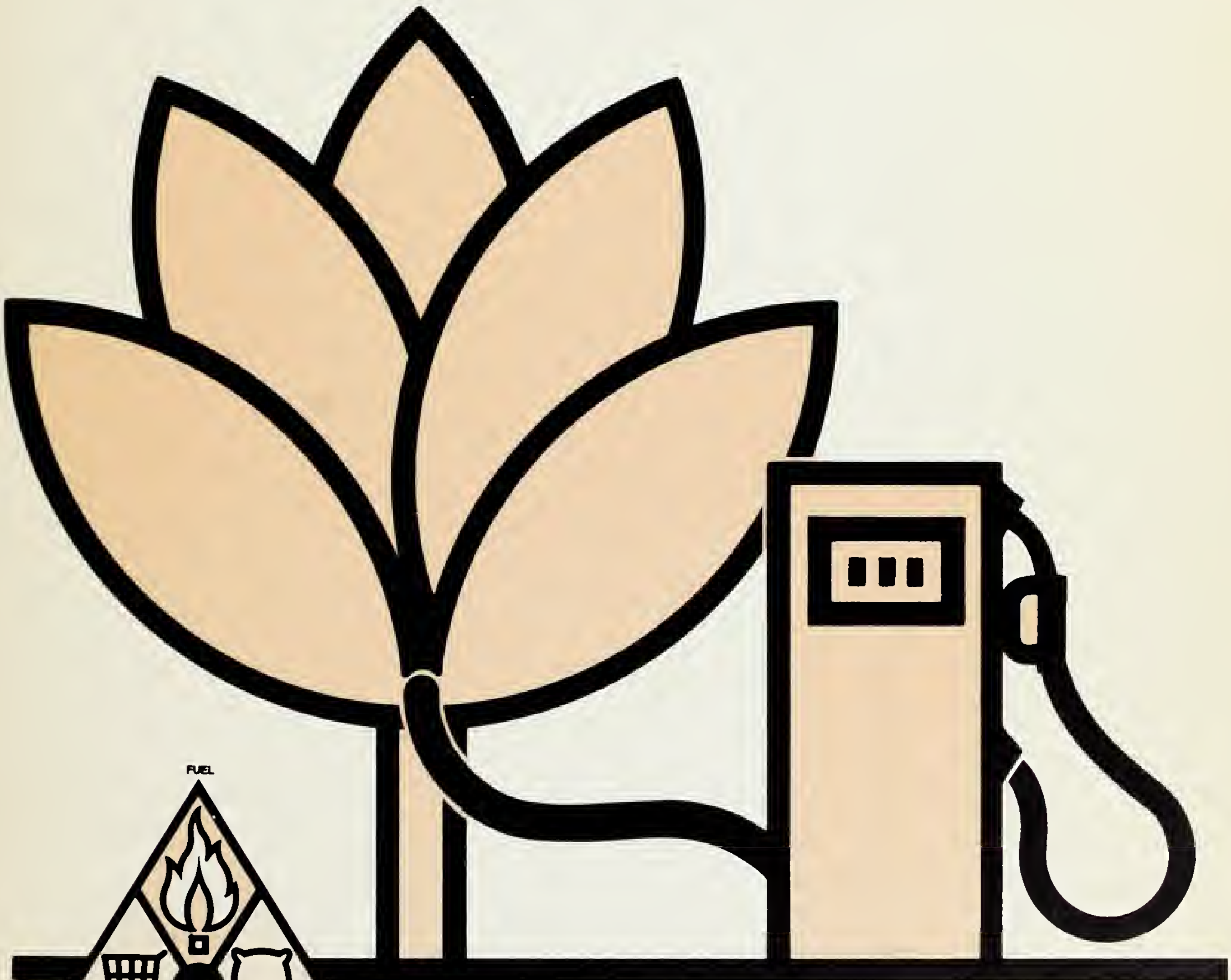
States
Department of
Agriculture

Small-Scale Fuel Alcohol Production



Small-Scale Fuel Alcohol Production

March 1980

United States Department of Agriculture
Washington, D.C. 20250

Prepared with the assistance of
Development Planning and Research Associates, Inc.
Manhattan, Kansas 66502

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GLOSSARY

alpha-amylase - an enzyme that acts specifically to accelerate the hydrolysis of starch to dextrins.

anhydrous - free from water.

anhydrous ethanol - 100 percent alcohol, neat alcohol, 200 proof alcohol.

azeotrope - a constant boiling mixture - for ethanol-water the azeotrope of 95.6 percent ethanol and 4.4 percent water boils at 172.7°F at one atmosphere pressure.

back set (also called set back) - the liquid portion of the stillage that is recycled as part of the process liquid in mash preparation.

beer - the fermented mash.

cetane number (cetane rating) - a measure of a fuel's ease of self-ignition. The higher the number, the better the fuel for a diesel engine.

dextrins - high molecular weight sugars, intermediates obtained in the conversion of starch to fermentable sugar.

denaturant - a substance added to ethanol to make it unfit for drinking without impairing its usefulness for other purposes.

enzymes - any of numerous complex proteins, produced by living cells, that catalyze specific biochemical reaction, e.g. glucoamylase and alpha-amylase.

flash point - the temperature at which a combustible liquid ignites when a flame is introduced.

glucoamylase - an enzyme that acts specifically to convert, by hydrolysis, dextrins to glucose.

hydrolysis - a chemical reaction of a substance with water that involves breaking of a bond and addition of water, e.g. starch reacting with water (in the presence of alpha-amylase) to form sugars (see saccharification).

octane number - a measure of the antiknock properties of a liquid motor fuel.

proof - a measurement of the alcohol concentration in an alcohol-water mixture, equal to twice the percentage of the alcohol, e.g. 80 percent alcohol equals 160 proof, 100 percent alcohol equals 200 proof.

saccharification - the breaking of complex carbohydrates (starch) into simple sugars (hydrolysis).

set back (also called back set) - the liquid portion of the stillage that is recycled as a portion of the process liquid in the mash preparation.

surfactant - surface-active agent, a substance that alters the properties, especially the surface tension, at the point of contact between phases, e.g., detergents and wetting agents are typical surfactants.

ADMINISTRATIVE SUMMARY

A. Introduction

Events in both agriculture and the economy at large appear likely to be dominated for decades to come by declining petroleum fuel supplies and rising prices for the major liquid fuels: gasoline, diesel fuel, LPG, and fuel oil. Furthermore, increasing dependence on petroleum imports from politically unstable regions of the world exposes all sectors of the national economy to unpredictable but extremely damaging interruptions in the normal availability of these fuels. Such interruptions can be especially disastrous in agriculture and food processing where liquid fuel needs are seasonal and cannot be postponed without the risk of losing entire crops.

In the distant future, technologies will probably emerge drastically reducing our nation's dependence on petroleum fuels. For the rest of this century, however, any realistic view of the situation indicates that the United States will remain heavily dependent upon petroleum-derived mobility fuels as well as upon interruptable supplies of imported crude oil. Liquid fuel supply uncertainty and rising fuel prices, therefore, must be accepted as facts of life for years to come.

It is in this context that the current intense national interest in biomass alcohol as a viable petroleum fuel extender or substitute has emerged. Technology for producing ethanol from agricultural commodities and residues is ancient and well known, although it has been used primarily for the production of beverages. Until recently, the relatively low prices of petroleum-derived fuels have prevented the application of this technology to the manufacture of fuel-grade alcohols, except in some countries during periods of war. But gasoline, diesel fuel and fuel oil prices are now rising rapidly relative to the cost of making alcohol from agricultural feedstocks, (in the process) fundamentally changing the outlook for alcohol as a mobility fuel.

The changed competitive outlook for alcohol fuels is reflected in national energy policy which now emphasizes various incentives designed to encourage rapid progress in the development of a domestic alcohol fuels industry based on the use of agricultural feedstocks. The more important elements of policy in this regard are the following:

- Provision of special tax incentives, such as the Federal Gasoline Excise Tax exemption for gasohol, to encourage the use of fuel alcohol;

- Provision of Government credit facilities to encourage investment in small and large-scale alcohol distilleries;

- Revision of alcohol regulations so as to make it easier for small-scale distillery operators to obtain licenses to build and operate stills;

- Allocation of substantial resources to research, development and demonstration programs designed to improve technology, reduce costs and accelerate commercialization.

The U.S. Department of Agriculture has important responsibilities in the implementation of national alcohol fuels policy, especially in regard to:

- Research and development focusing on the assessment of potential new agricultural feedstocks;

- Research and development designed to improve fermentation and distillation technology so as to reduce costs and fuel requirements;

- Demonstration and training programs to familiarize the farm community with available technology and to disseminate practical operating skills;

- Credit programs to assist the farm community in obtaining the financing needed to build fermentation capacity, especially small-scale stills.

On-farm and small-scale alcohol production and use are areas in which technical information particularly needs to be widely disseminated. Standards for small still construction and operation are not as established as for larger units, and the interest of the farm community in this area will not await development of standard design.

During the program planning phase of USDA's participation in the alcohol program, it became clear that there is a paucity of reliable technical and economic information on the production of fuel alcohol in small-scale stills. At the same time, it also became clear that USDA's field offices and the cooperative extension personnel would need a fairly comprehensive assessment of the state-of-the-art in this field as well as guidance on the economics involved if they were to administer the Department's alcohol program effectively. Accordingly, the decision was made in the summer of 1979 to commission preparation of this study.

While the purpose of this report is thus primarily to assist USDA offices in the administration of the Department's responsibilities in the fuel alcohol program, it is hoped that it will also prove helpful to investors and farmers contemplating construction of small-scale stills. A clear understanding of the purposes and limitations of this report is essential for the following reasons:

- In order to equip administrators to be of maximum assistance in the shaping-up of viable projects, the report concentrates heavily on the problem areas associated with the production and use of fuel alcohol via small-scale stills. The purpose is not to discourage people from investing in such stills, but rather to assist them in determining whether their circumstances are appropriate for such an investment and in making sure that their projects deal appropriately with these problems.

- The report deals with the existing state-of-the-art in the production and usage of fuel alcohol and does not indulge in speculations regarding the probable benefits of the massive research and development effort currently underway in the fuel alcohol area. The purpose is not to suggest that the problems identified in this report are permanent but rather to emphasize the fact that it is the existing, demonstrated technology that administrators, cooperative extension agents, and others face at this time as they implement USDA responsibilities and provide technical assistance for small-scale alcohol fuels.

- Since the report was prepared to meet an urgent near-term requirement, it does not attempt to offer solutions for many of the problems discussed nor to deal exhaustively or definitively with the subject at hand.

- Informed technical opinions on many of the topics discussed in this report differ widely and readers should not expect to agree on every point. The approach in the report has been cautious, in order to call attention to potential pitfalls.

As noted above, large amounts of private and public resources are now being devoted to research and development focusing on alcohol feedstocks, production technology, and problems associated with fuel alcohol usage. New cost-effective, energy efficient fermentation technology can be expected to flow from this effort. USDA and the nation's agricultural colleges and universities are focusing intensively on solution of the problems involved in the profitable utilization of fermentation by-products. These efforts, too, can be expected to yield results in the future. Substantial effort is also being made in both the public and

private sectors to resolve fuel alcohol usage problems. This effort, too, can be expected to yield technologies for improving the performance of anhydrous and non-anhydrous alcohols in existing vehicles and in the form of new engine designs that will be compatible with a wide range of fuels, including possibly straight alcohols.

USDA is optimistic about the probable outcome of current R & D in all of the above areas. For now, however, small-scale alcohol commercialization will of necessity rely mainly on existing, demonstrated technology. Hence, the importance of administrators and investors alike being well informed on the problems they will encounter as they participate in this important national program.

This report, then, balances the real potentialities involved in the production and use of ethanol with the most significant difficulties that must be overcome if such potentialities are to be realized. It examines the implicit difficulties that must be acknowledged and dealt with in the small-scale and on-farm production and use of ethanol. It also examines the costs involved and the returns to agriculture that can be anticipated. To accomplish this, the report estimates the relative costs of ethanol production from various agricultural feedstocks, the relative costs of various alcohol grades, the assumed economic returns, including those from by-products, and the value of varied farm uses of ethanol. Cost-return benefit analyses are presented based on a series of realistic model plant configurations that experience indicates will be most adaptable to agricultural needs and conditions.

This introductory chapter provides administrators, cooperative extension personnel, and others with an overview of the report as a whole. It includes a project evaluation check list, a tentative set of questions that implicitly offers guidance to those involved in the development and evaluation of small-scale and on-farm alcohol systems. Though not exhaustive, the check list can be used to prepare a reasonable estimate of the feasibility and costs of investment in specific projects. Administrators and investors will doubtless determine additional items they will want to include in the list. Each substantive chapter is prefaced with a more extensive summary of its major points, and the computer details providing the basis for the study are contained in the body of the report and in the appendices.

It is emphasized here that this report deals with technology that is rapidly evolving. Comments are invited to USDA's Office of Energy so that future editions can be modified and improved.

B. Assessment of Small-Scale Ethanol Systems

The key to successful, efficient small-scale ethanol production lies in the realization that the farmer must integrate his still into his farming system. Investment in a still will have implications for his financial ability to contemplate investments of other types, and also for how

Table 1. Relationships of model ethanol plant to farm size

	Ethanol			Corn			Stillage			Livestock		
	Year	Day	Yield	Year	Day 3/	Acres to produce	Year	Day 3/		Type	Feed	No. fed
	(000 gal)	(gal)	(gal/bu)	(000 bu)	(bu)	(@ 100 bu/acre)	--(1,000 units)--		% solids	(units/head/day)		
Pot still 1/	16	160 for 100 da	2.4	6.7	66.7	67	142.7 gal	1.427	9	NA	NA	NA
Small on farm 1/	60	200 for 300 da	2.5	24	80	240	376.8 gal	1.256	12.3	calf	5.1	246
										steer	7.5	167
										cow	5.85	215
										pig	1.0	1,256
Large on farm 1/	360	1.200 for 300 da	2.5	144	480	1,440	2,261 gal	7.540	12.3	calf	5.1	1,478
										steer	7.5	1,005
										cow	5.85	1,288
										pig	1.0	7,536
Small community 2/ wet	1,000	3,333 for 300 da	2.5	400	1,333	4,000	6,280 gal	20.930	12.3	calf	5.1	4,104
										steer	7.5	2,791
										cow	5.85	3,578
										pig	1.0	20,933
Small community 2/ DDGS	1,000	3,333 for 300 da	2.5	400	1,333	4,000	7,120 lb	23.730	90	calf	5.8	4,092
										steer	8.5	2,792
										cow	6.6	3,596
										pig	1.1	21,576
Large community 2/ DDGS	2,000	6,667 for 300 da	2.5	800	2,667	8,000	14,240 lb	47.470	90	calf	5.8	8,184
										steer	8.5	5,584
										cow	6.6	7,192
										pig	1.1	43,152

1/ Based on 190 proof ethanol production.
2/ Based on 200 proof ethanol production.
3/ Per production day.

he uses his time. The feedstock requirements for his still will influence his decisions regarding what crops to plant. The vital economic importance of by-product utilization will drive him to modify livestock feeding practices or to make arrangements for marketing by-products. He will also have to inform himself intensively on the options available to him for making effective use of the alcohol he produces. Most of these options will entail equipment modifications. He will also have to familiarize himself with applicable safety, environmental and insurance issues. Larger on-farm still operators will also have to deal with workmen's compensation matters. All of these problems are best dealt with in the planning stage, not after the fact.

With respect to the still itself, success will depend on a thorough understanding of the following operating factors:

- Production equipment
- Safety and quality control
- Feedstock options
- End-product utilization
- Fuel, water and utility requirements
- Cost of production
- Available financial incentives

To assist operators in selecting the optimum size of stills to fit into overall farming operations (or community stills), a list of strategic ratios relating alcohol production to still size, feedstock availability, and by-product utilization is given in Table 1. These factors, discussed in detail in subsequent chapters, are summarized and analyzed below.

Prospective small-scale still operators need to be aware that the basic simplicity of fermentation can be deceptive. In reality, the process requires considerable operating sophistication if satisfactory yields and product quality are to be achieved. While much of this sophistication can be obtained from experience, the learning process can be frustating and expensive if the operator does not invest heavily at the outset in acquiring a basic knowledge of the chemistry and operating procedures involved. This is especially important in regard to dealing with the ever present danger of contamination, which can drastically reduce yields, impair end-product quality, and render by-product stillage unusable. Strict attention to sanitation is as essential as the thorough training of operators.

1. Production Equipment

The types of equipment suitable for small-scale ethanol production may be divided into three groups--homemade stills, small, pre-packaged, on-farm units, and large on-farm and rural industry units.

Homemade equipment has many limitations. For the most part these units are small and usually pot stills. Their efficiencies are likely to be low. Product contamination may be a serious problem for equipment sterilization is most difficult. Too, such stills have safety-related problems. Frequently, they utilize open flames in their heating units, and, given ethanol's high flammability, they pose fire and explosion hazards.

The small, pre-packaged on-farm ethanol production plant seems to be the most feasible equipment for widespread adoption, but presently they have disadvantages. Only a few have been produced, although several manufacturers are planning production in the near future. Too, these plants have not been adequately tested and evaluated for extended periods. However, they do offer considerable efficiency and safety advantages over the homemade equipment if properly operated.

The large on-farm and community plants offer more advantages. They can produce 200 proof ethanol; they maintain lower production costs per gallon; and they will generate a continuous stillage production. Too, their economies will justify the employment of trained operators. Again, however, few of these plants are available now, and they are not well proven. More evaluation is needed to determine their actual operating parameters.

For purposes of this report, the characteristics of these units were used to construct six model plants for analysis. Details of these plants--pre-packaged pot still, small on-farm, large on-farm, small community (wet), small community (DDGS), and large community, DDGS--are given in Appendix A. A limited analysis was also made for a large plant having excess dehydration capacity to use in upgrading the lower proof ethanol from nearby smaller plants to 200 proof.

In addition to the various analyses made in this report, the study sought to determine what considerations would be germane to determining the feasibility of site-specific ethanol units, to determine, that is, what questions should be considered by any potential producer. These questions, which cannot be answered in the abstract, would include:

- Does the potential system balance numbers and types of livestock with the anticipated stillage availability to maximize its feed value?

- Is there a potentially sensible production schedule of plant operations to balance personnel with ethanol production and stillage feeding?

- For a continuous operation plant is there a thorough housekeeping and maintenance procedure so planned as to eliminate or minimize breakdowns, bad batches, and contamination?

- Is there a thorough enough understanding of plant and product safety considerations to avoid danger? Is there available, well-located safety equipment--fire extinguishers, alarms, and other devices?

- Is the potential plant's available water quality and quantity adequate for both processing and cooling operations?

- Will all the requirements of BATF be complied with? Can plant equipment be adequately insured with casualty and liability insurance?

A more complete check list is included in Section C.

2. Feedstocks

The starch and sugar-containing raw materials considered for ethanol production via fermentation are small grains, potatoes, sugar crops and crop residues like overripe fruit. Their production and availability vary. The small grains, produced in large quantities, are potentially available year-round, predominantly in the Midwest. Present potato production is centered in the Western regions. In a controlled atmosphere, potatoes may be stored for sufficient periods of time to allow year-round ethanol production. Sugar cane is primarily produced in the South; the production of sugar beets is more widespread. The fairly rapid deterioration of these crops dictates that processing be seasonal. Waste materials are quite site specific and usually seasonal in nature. These variations in availability by region and season have implications for the location and size of specific types of ethanol production plants.

As the present production of these crops is primarily committed to feed, food, industrial, seed, and export markets, the calculated cost of feedstock in ethanol production was based on the price in those markets, and based on these historical costs, small grains provide the least cost per gallon of ethanol produced. The prices for grains vary somewhat with that for corn being \$1.14 per gallon. Ethanol from sugar beets is calculated to be \$1.43 per gallon and that from potatoes is \$4.35 per gallon. If animal feedstock production became extensive, these prices could vary, perhaps significantly.

3. Product Utilization

a. Ethanol

With present technology, farm stills are limited to the production of 190 proof, or lower, ethanol. These products contain at least five percent water, a quantity of water too great to allow mixing the alcohol with gasoline to produce "gasohol." The 190 proof material, however, can be used in most heating applications where distillate type liquid fuels are used--water heating, space heating and grain drying.

Less than 190 proof alcohol can be used in most spark ignition engines, including those for automobiles, trucks, and tractors. Such engine modifications will be required as:

- the resetting and advancing of the ignition timing,
- the readjusting or replacing of the carburetor jets, and
- the providing of preheating for cold weather starting.

Alcohol fuels have high octane ratings and may be used in higher compression engines than those designed for gasoline. Engines designed for propane (LP) or natural gas fuels can use alcohol efficiently. If alcohol fuels become more common, conversion kits may become available for existing engines. Also, new engines, those designed for the most efficient use of alcohol fuels, will probably become available if alcohol is abundantly produced. Such engines could not use gasoline.

Alcohol fuels have high octane numbers, but their low cetane number makes them generally unsatisfactory as a sole fuel for diesel engines; however, modification kits are available to allow some alcohol use. After modification, alcohol is added through a carburetor mechanism to the air stream, and diesel fuel is injected as normally. The process allows about 30 percent of the engine energy requirements to come from alcohol. Cetane improvers are being investigated and may become available in the future. If so, this would allow direct use of the ethanol.

Some minor problems will result from alcohol substitution for gasoline. Engine fuel tanks may rust rapidly, and new fuel tank materials will have to be developed. Some plastics, such as gaskets, are soluble in alcohol and will have to be replaced.

Overall, for 190 proof ethanol, on a gallon (volume) basis:

- One gallon of alcohol will substitute for 0.66 gallon of gasoline.
- One gallon of alcohol will substitute for 0.52 gallon of diesel fuel.

Larger plants which can produce 200 proof ethanol will have a wider potential market. This material can be blended with gasoline to produce gasohol, and gasohol can be used in most spark ignition engines with little or no modifications or problems. The 200 proof material will have the same limitations as 190 proof if used alone in spark ignition engines. It will not be a suitable fuel for diesel engines if used alone unless cetane improvers are developed.

b. Farm fuel use

Farm use by type for various farming operations is not available. Most farm-record associations show fuel, oil, and grease as one expense item. Approximately 85 percent is for fuel.

Illinois farm expense records show an expense of $10,700 for fuel oil and grease for grain farms averaging 1,400 tillable acres in 1978. Farms of this size represent less than 3 percent of the over-50-acre farms in Illinois.

In 1978, the average U.S. wholesale price for No. 2 diesel fuel was $.37 per gallon; the average wholesale gasoline price was $.65. If the average farm fuel (gasoline and diesel) price in Illinois was $.50 per gallon, then these 1,400 acre grain farms used about 18,000 gallons of liquid fuels. The smallest still considered in this study would supply the fuel needs of these 1,400 acre farms. Most stills would supply the needs of more than one farm.

c. By-products

The two by-products of ethanol production are carbon dioxide and stillage, a thin slurry containing approximately 10 percent solids. The former by-product, carbon dioxide, will have little value from its production in small farm stills. Stillage, however, may be used directly as a food supplement or may, by further processing, be marketed as distillers dried grains (DDG).

Used directly, stillage has a limited but accountable value for on-farm use as animal feed. Marketed at a very low price by the beverage industry, its value as protein is realized only when it is utilized in a properly balanced ration and when its considerable water volume does not exceed the normal water requirements of animals.

A dependence on stillage has distinct disadvantages that limit its utility. Since feeds containing large amounts of stillage will have very distinct physical and palatability characteristics, its use must be constant, for intermittent use will frequently cause high production animals to go "off feed." Too, stillage, because it deteriorates rapidly and loses its nutrient value, should be fed within twenty-four hours. Doubtless, such use characteristics can be offset by refrigeration or similar preservation measures, but for small, farm stills, such additional costs to assure continuous and sufficient feed supplies may well be prohibitive. Doubtless, too, the need to modify feeding equipment and to prevent stillage slurry freezing in many farming areas will but add to feed costs.

Stillage can be processed to extract its ten percent solids and concentrate them into distillers dried grains, a product of relatively significant market value because of its protein content, about 27 percent (cf. soybean meal at

44 percent). DDG can be fed directly to ruminant animals, and when it is fortified with lysine, an important amino acid, it can replace soybean meal rations for swine and poultry. DDG is an easily marketed product; in the long-term, marketing large quantities could affect overall feed ingredient prices, especially those for soybean meal.

The pricing of stillage and DDG is a result of their production and transportation costs. Doubtless, to individual farmers the values of the products will vary and will reflect the production potential of on-site and area markets. The January, 1980, DDG price approximated $145 per ton, a price lower than that of soybean meal at $185 per ton at Chicago; however, the lower protein content of DDG requires a greater volume of its use and a resulting use price greater than that for a soybean meal equivalence. Note, however, that DDG normally sells at a price above that of soybean meal per unit of contained protein.

If the nutrient value of stillage solids is calculated also at $145 per ton, a comparable stillage price will be $.06 per gallon. Most farmers, however, cannot purchase at bulk wholesale prices. Their generally 30 percent higher unit prices for the protein complement of a feed supplement would, consequently, increase stillage values from on-farm still production to $.07-$.09 per gallon.

Table 1 shows some of the relationships of the different size models of stills to feedstock requirements, ethanol production, and the numbers of animals which can be fed with the projected models' by-products. The efficient use of stillage would obviously require a reasonable balance between its production and the numbers of animals that would utilize it.

4. Fuel, Water and Utilities

A significant determinant in any decision to produce ethanol is the cost of its production, and this in turn depends upon the forms of process fuel used, the type of alcohol produced, and the extent of by-product processing employed.

The energy used to produce ethanol is high in relation to the energy contained in the ethanol. If the feed by-product is not dried, then considerable quantities of energy can be saved, and if 200 proof ethanol is produced, the energy requirements are increased. The following energy requirement estimates are characteristic of a one-million gallon per year plant.

Product	Btu/gallon
190 proof, wet by-product	43,000
200 proof, wet by-product	61,000
200 proof, dry by-product	82,000

Since one gallon of 200 proof alcohol has a heat content of 76,152 Btu, it is obvious that the energy required to produce ethanol is almost equal to that obtained. For this reason, energy conservation cannot justify the production of ethanol. However, ethanol production can be viewed as a means of converting the relatively plentiful supply of solid or gaseous fuels--coal or methane--into those liquid fuels that are most compatible with mobile engine requirement.

Other fuels have been considered. The price and the availability of coal and its relative ease of processing make it the most logical fuel for consideration; however, for small farm stills, many practical difficulties will inhibit its use. Boilers which can use wood, crop residue or other biomass materials are not readily available in the sizes needed for the farm and rural plants considered here but are under development. In the near term this will be a constraint. Proposals to use crop residues as daily fuels have failed to consider their long-term effects on soil fertility. A study published recently by the Agricultural Extension Service in Nebraska warns of the danger of crop residue removal over most of the state, and the costs of such soil degradation have not been accurately determined. Feedlot or other farm wastes can be used to generate methane gas which could serve as a fuel for ethanol production or other stationary uses, but their technology and costs are not well developed. Solar stills have been considered and limited developmental work has been done on them, but the technology will not be available in the short to medium term. Some industrial processes such as those to produce carbon black or bricks have large amounts of waste heat that could be utilized on a site specific basis. Cogeneration of electricity with process steam from wasted heat is a possibility, but this would require a specific designing of a combination electrical generating facility and ethanol plant.

One of the most limiting constraints to ethanol production on a site-specific basis is an adequate supply of water. A minimum of five gallons of potable quality water per gallon of alcohol are needed in the process. Additionally, greater quantities of water of lower quality are needed for cooling. If well water is not available for cooling the fermenting mash, then mechanical refrigeration would be required at considerably increased investment and operating costs. This constraint is so great that many beverage distilleries close for one to two months during summer.

If underground water is readily available (at a temperature of 50^{o}F), then about 7 gallons will be required per gallon of ethanol; hence, the total well water supply needed for process and fermentation cooling is about 12 gallons per gallon. For the one-million gallon per year plant this is 12,000,000 gallons annually or 40,000 gallons per day. Furthermore, if well water is used for condensing and other cooling and enters the plant at 50^{o} and leaves at 100^{o}, then an additional one hundred gallons per gallon of alcohol is required. For the one million gallon per year plant, this amounts to 360,000 gallons per day or 330 acre feet per year. A plant of this size, however, might economize on water by installing cooling towers or a pond.

Normal utilities such as electrical will present no unusual problems.

5. Costs and Subsidies

Determining the economics of ethanol production involves considering its cost of production and its fuel value. Both values are very much dependent upon circumstances. Specific plant size, product proof, and the presence or absence of stillage drying facilities are major factors in the cost of production. Additionally, conditions unique to a given farm or site will affect costs. The farmer's perception of the value of his labor, feedstock, and capital costs will be of particular importance. Fuel values vary, depending upon

application and the fuel being replaced. Here, too, the farmer's perception of the value of gasoline, diesel, and LP gas will be factors. The shadow value prices of gasoline and diesel may be very much higher to the farmer than would be the general market price during critical periods of crop operations in the event these conventional fuels are unavailable.

At market prices, the cost of production in small-scale ethanol plants exceed the fuel values in all applications computed. As shown in Table VIII-1, the range of this deficit is \$.47 to \$1.29 per gallon and is generally in the \$.47 to \$.87 per gallon range. For gasohol applications, the deficit could be lowered by about \$.10 per gallon; however, to realize this credit base, gasoline stocks with lower octane ratings would need to be used.

The table does not show production costs for 100 and 160 proof in the larger on-farm or the community stills. Considering size economies, the diesel application difference would appear to be reduced to \$.20 per gallon.

As discussed in the first paragraph of this section, site specific circumstances and farmer perceptions of input and fuel values could change these differences in given situations. It should also be noted that Congress is considering incentives for on-farm production and use of alcohol that could substantially offset these differences.

C. Guidelines to Assess the Feasibility of Ethanol Plant Designs

The following check list may be used to determine the feasibility of a tentative decision to institute small plant ethanol production and to record the data necessary to seek a financial loan for such an investment. The list should serve three specific functions: 1) to remind the potential producer various points that must be considered; 2) to record certain information regarding a plant's broad and critical performance specifications; and 3) to provide a brief financial summary of a plant's potential production costs.

This check list is not intended to be completed by the farmer alone. If such farmer intends to purchase a prefabricated and packaged unit, the manufacturer would assist in the preparation. If a custom-designed unit is to be constructed, then a professional, such as an engineer, will be required, and this advisor should be able to assist in completing the check list. A person who plans to design and construct his own still should become familiar enough with alcohol production to complete the check list.

The check list was designed to allow for relatively few constraints on the plant designer. This was to provide the opportunity for different designers to take relatively creative approaches to most design details. Similarly, the type of feedstock is not prescribed although grain was primarily considered. Fuel sources could be of various types (but the use of petroleum fuels would not contribute to increasing the fuel availability of agricultural fuels). Coal, wood, or crop residues would be preferred fuels.

Operator training will be important in a successful operation. This training has not been specified, but it could be provided by equipment or input suppliers, the State Agricultural Extension Service, or any of a variety of public institutions and agencies.

Check List Commentary

- The questions in Section 1, "Facility Resources," should in general be answered affirmatively if the proposed plant design is feasible at its intended location.

- In considering the questions in Section 5, "Process Performance Specifications," the tentative ethanol producer should keep in mind the following considerations:

  a. One gallon of 190 proof alcohol contains 72,345 Btu. Boiler fuel heat will be about equal to this for stills which produce 190 (or lower) proof alcohol. Stills producing the 200 proof alcohol, which is required for blending to make gasohol, given present technology, will use more energy per gallon than will be yielded by the alcohol, with present technology.

  b. There is no "correct" answer for cost of fuel per gallon of alcohol.

  c. Grains such as corn yield about 2.6 gallons of 200 proof alcohol per bushel. Any yield below 2.0 gallon per bushel of grains which have test weights exceeding 55 pound per bushel would be considered low. As a practical mater 2.5 to 2.6 gallons per bushel is about the best that can be expected with small stills.

  d. There is no "correct" answer to the rate of production. This will depend upon the needs of the person owning the still, but an equipment supplier should guarantee a production capability.

- In considering Section 6, "Supply Requirements and Services." the person planning ethanol production must anticipate the use of greater treatment capacities than those typical for household purposes. The water mineral content in large boiler use designs should be checked by a feedwater chemical treatment supplier.

- The Section 7, "Weekly Labor Schedule" is provided to insure that all labor requirements have been considered. Small, pot-type farm stills will probably require about one hour to prepare the grain for one batch. Cooking requires at least four hours of almost continuous attention per batch. Fermenting time per batch is about three days but requires little attention. Distillation time varies, but it does require close attention. Most pot stills will require 4 to 8 hours to distill one batch. The boiler will require attention during both cooking and distillation.

- In Section 8, "Utilization of Product," there are no "correct" answers. Obviously, however, production should be scaled to accommodate projected uses or markets.

- In considering Section 10, "By-Product Recovery," the plant design should keep the following observations in mind:

  a. With no set back one bushel of grain should yield approximately 30 gallons of stillage of 8-10 percent solids or about 16-18 pounds of grains (dry weight).

  b. If stillage is not produced every day, its value will be very low because it would have to be fed to low production animals. High production animals would go "off feed" by irregular applications. For intermittent production, a gallon of stillage might have about the same value as one pound of hay. For continuous production, three gallons of stillage should have a value about equal to one pound of grain plus one pound of soybean meal (or similar protein supplement). The greatest value will be obtained when feeding young beef animals (under 650 lb), dairy cows, or hogs.

Check List of Design and Performance
Criteria for Small Still Alcohol Plant
Loan Applications

1. Facility Resources:

a. Water Requirements:

(1) Well water (or similar sort) with a capacity of 125 gal/day, per gal of daily alcohol capacity, or
(2) Well water with a capacity of 25 gal/day, per gallon of alcohol/day plus cooling pond of minimum depth of 6 ft and surface area of 2,000 sq ft (.04 acres) per gallon of alcohol produced per hour (a cooling tower may be used instead of cooling pond)
(3) Pump(s) and storage tanks as required
(4) Boiler and process water treatment facilities as required

Considering the above requirements:
Is well water available? Yes ____ No ____
Will water be purchased? Yes ____ No ____
Will a cooling pond be required? Yes ____ No ____
Is cooling water pond available if required? Yes ____

b. Land:

Is land area available for storage facilities for:
Feedstock? Yes ____ No ____
Product? Yes ____ No ____
Fuel? Yes ____ No ____
By-product? Yes ____ No ____

Can the plant be isolated from other buildings for fire protection? and safety? Yes ____ No ____

c. Buildings: Are buildings available for the following process and materials storage design options?

(1) No building (depending on equipment and climate)
(2) Boiler, cooking and fermentation areas with distillation out-of-doors
(3) Boiler, cooking and fermentation in one building and distillation in separate building. Building housing distillation must have explosion proof electric wiring and meet other insurance requirements.

Do buildings for the proposed options exist? Yes ____ No ____
If needed, can additional facilities be provided? Yes ____ No ____
Is a 15 day supply of feedstock storage with handling equipment available? Yes ____ No ____

Are facilities to store enzymes, yeast, chemicals, and boiler fuel, available? Yes ____ No ____

Has an insurer certified that the various equipment and buildings suggested above are insurable against casualty or liability losses? Yes ____ No ____

Feedstock Preparation Equipment: Are or can the following be available?

Is hammermill or other grinding equipment available? Yes ____ No ____

Is meal bin for processed feedstock available? Yes ____ No ____

Is scale or other measuring device available? Yes ____ No ____

2. Process Equipment and Specifications: The following process characteristics, where applicable, must be realizable.

a. Boiler Needs:

A capacity to supply peak heat requirements for process
Air pollution control equipment as required depending on fuel
A deareator
Feedwater treatment facilities
An automatic feedwater pump

b. Cooking Equipment and Design:

A cooking tank capacity of 15 gallons per bushel + 25 percent
A tank capacity equal to 30 gal/bu grain + 25 percent if used for fermenting
Tank bottoms coned or sloped to drain
An agitator
A steam sparging device
Equipment designed for easy cleaning
Cooling by coils, plates, jackets, etc. as required

$$\text{Heat required} = \frac{\text{Gallon of mash} \times 8.3 \times 150}{\text{hrs to heat}}$$

(These heat requirements can be reduced by designs that allow the reuse of hot, thin stillage)
A transfer pump (centrifugal or other) as required

c. Fermentation Tank Equipment and Design:

A tank capacity of 30 gal/bu + 25 percent
A tank sealed from atmosphere and provided with CO_2 vent
Cooling coils as required
An agitator
A transfer pump
Equipment capable of sterilization by washing and steaming
Material: Fiberglass, steel or other suitable material
Tank bottoms sloped or coned to bottom drain with, preferably, rounded corners
A total capacity to support required distillation

d. Instrumentation Equipment:

A pH meter or other indicator
Temperature indicators for cooking, fermentation and distillation
Temperature controllers if plant designed or intended for automatic operation
An hydrometer for testing proof
A starch tester
A sugar tester

e. Distillation and Rectification Equipment and Design:

A beer well if required by process design
A stripper column required if alcohol is not distilled from fermentation tank
A rectification column (stripping and rectification can be combined in one column of sufficient height)
Columns of stainless steel or heavy mild steel to insure life of 5 years (at least ¼" plates + 3/16" tube wall)
An heat exchanger or steam sparging device to heat beer
A liquid level indicator in stripping column
A means for simultaneous control of temperature and level of liquid in stripping column
Provisions for daily and periodic cleaning of stripper column
A fusel oil withdrawal tap
A reflux pump if two columns
A condenser for vapors with suitable cold water coils and liquid (reflux) recirculation control
A pressure gauge
A safety valve
Temperature indicators (minimum of 3)

Distillation (rectifying) column capacities for the indicated volumes are about:
9 in diameter up to 25 gal alcohol/hr
12 in diameter up to 40 gal alcohol/hr
16 in diameter up to 70 gal alcohol/hr
24 in diameter up to 160 gal alcohol/hr
Column heights depend upon plate spacing and cannot be specified
Packed columns require special considerations

f. Dehydration of Alcohol Equipment:

If greater than 192 proof is to be produced, a proven dehydration system must be provided.

g. Denaturization Equipment:

Means for adding denaturant acceptable to BATF

3. Alcohol and By-Product Storage and Handling Equipment and Design:

a. Alcohol Storage:

Mild steel containers are acceptable
A desiccant type vent cap on containers
A means for unloading containers
Metering equipment as required by BATF

b. Stillage Storage and Handling Equipment:

Containers equal in capacity to batch size or daily stillage production
A refrigeration system if production does not occur every day and stillage is fed to high production animals; such preservation equipment is not required for low production animal feeding
An agitator
An unloading pump

Drying Equipment:

Adequate drying equipment if stillage is dried

Wastewater Treatment Facilities:

A means for disposing of washwater, spills, and accidental runover

4. Ancillary Equipment:

Safety Equipment:

Fire protection equipment
Product security as required by BATF
Federal and state personnel safety requirements design

Lighting Facility:

Adequate light to operate equipment

5. Process Performance Specifications:

How many Btu of input fuel will be required per gallon to produce 190 proof (equivalent) alcohol? ________
What will be the cost of fuel per gallon of alcohol? ________
How many gallons of 190 proof (or higher) can be produced per bushel of grain (or other feedstock)? ________
How much alcohol can be produced:

________ gallons/hr ________ gal/yr

________ gallons/day

Who will certify to the above performance specifications?

____ a. Equipment manufacturer of entire system guarantees and furnishes performance bond (or delays 50% of invoice for payment until performance specifications have been met)

____ b. Design and supervision of construction will be by a registered professional engineer, an extension service engineer, or an equivalent professional.

____ c. Other than a or b, (Federal funds will be obligated but not dispersed until performance is proven)

6. Supply Requirements and Sources:

Boiler feedwater treatment - supplier ____________________
Boiler feedwater treatment cost/gal alcohol ____________
High temperature (liquifying) enzyme supplier ____________
Cost/gal alcohol ____________

Saccharifying enzyme supplier ____________________
Cost/gal alcohol ____________

Yeast supplier ____________________
Cost/gal alcohol ____________

Denaturant as required by BATF
Denaturant supplier ____________________
Denaturant cost/gal alcohol ____________

Neutralizing agents
Acid supplier ____________________
Cost/gal alcohol ____________
Base supplier ____________________
Cost/gal alcohol ____________

7. Weekly Labor Schedule:

Day	Prepare feed-stock	Cook	Ferment	Distill	Dispose of by-product	Firing Boiler & Other	Total* hrs/day
Monday							
Tuesday							
Wednesday							
Thursday							
Friday							
Saturday							
Sunday							

Total hrs/week ________

* Some jobs may be combined or done simultaneously

8. Utilization of Product:

Automobile use ________ gal/yr ________ Proof
Will engine be modified? ________ cost $________

Truck use ________ gal/yr ________ Proof
Will engine be modified? ________ cost $________

Gasoline tractor use ________ gal/yr ________ Proof
Will engines be modified? ________ cost $________

Diesel tractor use ________ gal/yr ________ Proof
Will engine be modified? ________ cost $________

Other uses
__________ gal/yr for ___________
__________ gal/yr for ___________
__________ gal/yr for ___________

Amount to be sold/yr ____________
To whom sold _________________

9. Feedstock Cost: (i.e., The price of grain divided by the expected yield.)

Grain kind ___________
Cost/bu ___________
Gallons/bu ____________
Cost/gallon of __________ proof alcohol __________

Other:
Kind _______________
Cost/ton __________
Gallons per ton __________
Cost/gallon of ___________ proof alcohol ___________

10. By-Product Recovery:

Form: _________ wet stillage _________ dried product

Quantity available/day ________ gal. stillage
________ lbs dried

Disposition:
__________ Feed
__________ Other (specify)

If wet stillage is fed, will water intake exceed 1 gallon/2 lbs solid feed? Yes ____ No ____

Value of: ________/gallon of wet stillage
________/lb of dry product

Value of by-product/gallon of ____________ proof alcohol $____________

Do you have any intended use for CO_2? Yes ____ No ____
If yes, what?____

11. Electrical Requirements:*

List major motors (greater than 1HP) only

Grinder motor	______ HP	______ Hrs/week	______ kWh
Conveyors	______ HP	______ Hrs/week	______ kWh
	______ HP	______ Hrs/week	______ kWh
Pumps: #1	______ HP	______ Hrs/week	______ kWh
#2	______ HP	______ Hrs/week	______ kWh
#3	______ HP	______ Hrs/week	______ kWh
#4	______ HP	______ Hrs/week	______ kWh
#5	______ HP	______ Hrs/week	______ kWh
#6	______ HP	______ Hrs/week	______ kWh
Agitators	______ HP	______ Hrs/week	______ kWh
	______ HP	______ Hrs/week	______ kWh
	______ HP	______ Hrs/week	______ kWh
Air compressor	______ HP	______ Hrs/week	______ kWh
Lighting			______ kWh
Other			______ kWh
		Total kWh/gal	______

* Assume 1 kWh per horsepower hour of operation

Electrical Rate ______/kWh

Electrical cost/gallon $__________

12. Purchased Water Requirements:

Gallons/gallon of alcohol for processing __________

Gallons/gallon of alcohol for cooling __________

Cost/gallon of water __________

Cost/gallon of alcohol __________

Summary of estimated operating costs:

			Cost per gallon alcohol
Direct Costs			
Feedstock		______	
Less credit for stillage	______		
Less credit for CO_2	______		
Total credit		______	
Net feedstock cost			______
Labor			______
Fuel			______
Electricity			______
Water (purchased)			______
Supplies (yeast, enzymes, etc.)			______
Other			______
Total direct cost			______
Indirect Cost			
Maintenance _____ per year			______
Supervision _____ per year			______
Taxes (property) _____ per year			______
Insurance _____ per year			______
Depreciation			
Total investment _______			
______ years _______ per year			______
Total indirect costs			______
Total Costs - Direct and Indirect			______

Note: There are no "correct" answers for operating costs except that the cost per gallon of alcohol should not be greater than its value to the farmer.

I. INTRODUCTION

Alcohols have long been considered a feasible motor fuel. The Otto engine, the first successful internal combustion engine built in 1876, could use alcohol. Indeed, Henry Ford built the Model T with an adjustable carburetor so that it would run on alcohol or gasoline or a mixture of the two. Interest in the United States in alcohol fuels, particularly ethanol--the subject of this report--has generally been more frequent during times of low grain prices; however, special national circumstances such as World War I, World War II and more recently the "energy crisis" have also forwarded such interest.

Production of fuel alcohol appears to be developing with a large variety of plant sizes envisioned. Ethanol production in small-scale plants, either individual on-farm units or small community plants, has been discussed at length in the news media. Much has been stated about the possible general types of facilities that would be required if the farmer were to produce fuel grade alcohol; however, to date apparently very little alcohol has been produced by such plants.

Reasons have been suggested that may favor the development of small-scale plants:

- Farmers may place a lower value on their own grain than the price they would receive in normal commercial channels
- Farmers may have cheaper energy sources, e.g., crop residue, than can be practically used in large plants
- Farmers may use the by-product wet stillage in their own feeding operations and avoid the drying, transportation and marketing costs included in commercially produced feeds
- Farm labor costs are quite low during some seasons
- Farmers may attach a high value to fuel "self-sufficiency."

Assembling the available information on types of ethanol production facilities and their characteristics and capabilities is required in order that an analysis can be performed to determine the feasibility of small, commercial and farm ethanol production units.

A. Purpose

This study will identify

- the available fermentation and distillation technologies usable for small-scale and on-farm production of ethanol from farm products and wastes and describe their economic and technical characteristics,

- the appropriate types and sizes of farms suitable for the introduction of such ethanol production units, and
- the conditions, both financial and non-financial, that would influence the formation of such systems and their widespread development.

B. Scope

The study was limited to the consideration of small-scale ethanol production units: on-farm units producing up to 360,000 gallons per year and small-scale, community plants producing up to 2 million gallons per year. Feedstocks were limited to those containing starches and sugars (no consideration is given in this study to cellulosic feedstocks). As most current technologies utilize grain, primary emphasis will be given to using grain as the feedstock and the evaluation of other feedstocks use will be limited.

The factors influencing introduction of dispersed, small-scale ethanol production facilities are to be characterized and evaluated and will include the availability of the production equipment, its technical capabilities and costs, the suitability of alcohol for major on-farm energy applications, and ultimately, the types and sizes of farms and community operations for which ethanol production is appropriate.

To assess the potential production of ethanol from farm products and residues the study examined availability of both commercially produced equipment and equipment components for assembly by the owner. (The study also considered the suitability of the detailed information required for such assembly by the operators.) Too, the capabilities of this equipment, its flexibility for utilizing a variety of feedstocks, the extent to which the equipment has been tested, and the actual efficiencies of its operation were determined. Information on the investment required for equipment, on operating and maintenance costs, and on the feedstock costs were estimated or compiled and analyzed. Other factors affecting the alcohol costs of production, such as by-product utilization and administrative and regulatory requirements were evaluated.

The study, furthermore, analyzed the liquid fuel requirements in relation to the size and type of farm. Inherent in this assessment was a consideration of regional differences and variations in fuel consumption and in feedstock types and availability.

Finally, the general design criteria for small-scale alcohol production systems were delineated.

The study was limited to ethanol production in small-scale units located either on individual farms or in a central area location. As a consequence and because the size of a production facility can dictate the proof of the alcohol produced, this study also considered the effect that the size and sophistication of the plants would have on the stability and marketability of their by-products.

Although the livestock numbers required for feeding wet stillage were evaluated, no consideration was given in this study to the possible generation of methane via digestion of animal wastes for use as an ethanol process fuel.

C. Limitations

The major limitations on the study were those that resulted from the lack of actual operating data for the sizes and types of ethanol production facilities considered. To date only prototype equipment has been constructed. The capabilities and design criteria for these prototypes were assembled from knowledgeable individuals including representatives of 17 small-scale production alcohol equipment manufacturers and/engineers working on designs for alcohol fuels plants. Based on this information, preliminary investment and operating costs were estimated. The investment costs were based on the assumption that the equipment would be repetitively produced. (In fact, of course, early prototypes might be the more expensive.) The available information is incomplete for very few plants are operational. As plants begin operating on a regular schedule, this study's cost data may be adjusted, as necessary, by actual data. Technology advancements for feedstock conversion rates and expected yields, plus the use of multiple feedstocks and energy sources will change the production efficiency and costs of production. At the present time, no actual values are available.

Conversion rates were estimated to reflect those that should be attained by trained operators; however, it is not known if these rates will be realized in practice.

In determining plant throughput, a maximum utilization of equipment was assumed. Without actual operating data, it is impossible to judge if this assumption is reasonable over the expected life of the plant.

For those feedstocks that have a short season, equipment designed for multiple feedstock would be desirable. No data were available to assess this type of plant.

Energy inputs were calculated from energy balance studies. Energy costs were based on relatively well-known technologies that utilize conventional fuels. No information was available that would allow an evaluation of equipment utilizing alternative fuels use such as biomass burners and solar stills. In addition, data were unavailable to permit an evaluation of water-alcohol separation technologies such as membrane separation, vacuum distillation, and absorption dehydration that could result in significant decreases in energy use.

Other limitations were those due to the lack of information on the utilizaton of 200 and lower proof ethanol and ethanol blends in engines and burners. For example, the long term effects of ethanol use on engine wear are unavailable. Little research has been done on non-gasohol applications. For example, required conversions and modifications and their associated costs have not been fully evaluated.

An associated limitation was the lack of information on the feeding of wet stillage. No detailed animal feeding trials have been conducted to determine the most efficient methods of feeding wet stillage. Nor has any research been conducted to determine the long-term effects on animals of feeding wet stillage. The values of wet stillage in a diet for specific animals were estimated entirely on the basis of nutritional information extrapolated from DDGS nutrient content.

These constraints point directly to research needs such as those below. Technological advancements could significantly affect the estimates used in this study.

D. Research Needs

Present data concerning ethanol are limited: most information is closely held within existing companies and is primarily reflective of beverage alcohol production.

A definitive assessment of fuel ethanol production in small scale units would require data reflective of the following concerns:

- The degree of fineness needed when grinding grain. Beverage distillers usually quote the size of hammermill screen but they probably use normally dry grain at 15 percent moisture or less. Wetter grain which could be purchased at a lower price (reflecting the cost of drying) would have different grinding characteristics. The coarser particles would undoubtedly affect the cooking and conversion processes.

- The optimal amount of set back. Liquid from the stillage which can be set back (recycled) in the process is an important problem. If more liquid is set back to be used in the next batch, the cost of drying by-product will be reduced or the more concentrated stillage would have a lower transportation cost. Greater set back will probably have some effect on the overall process including the quantity of enzymes and yeast required.

- The efficacy of enzymes and yeasts. Although one publication shows very wide differences in various yeast strains, the efficacy of various enzymes and yeasts has not been widely reported in published literature. Beverage alcohol distilleries have probably been more concerned with flavor than with efficiency and yield.

- The cooling water required. Cooling water requirements are critical. For farm and small stills, ponds are probably more practical than cooling towers. Little literature is available and computational methods for engineering design differ widely.

- The efficiency of the distillation process. The distillation process appears to be relatively energy inefficient. The output of the first distillation column is recirculated and revaporized two or three times in some designs. More research is needed to optimize the design of the system of distillation to balance equipment with energy costs.

- Production of 200 proof ethanol. Dehydration of alcohol from 190 to 200 proof is very energy intensive. New techniques, such as molecular sieves, need development as possible alternatives to the commonly used benzene distillation system.

- The utilization of lower proof ethanol in blends. Gasoline-alcohol mixtures, gasohol, require the use of 200 proof ethanol; 190 proof is much cheaper but the alcohol-water layer will settle out when it is mixed with gasoline. If an emulsifying agent can be found which will keep the three materials (gasoline, alcohol and water) mixed then about one-fifth of the energy required could be saved.

- Separation of solids from stillage. Centrifuges or screens are normally used to remove the solids from stillage. These are very expensive machines to buy and operate. It should be possible to develop less expensive equipment and/or procedures to accomplish this task.

- Drying wet grains. Drying wet grains uses about one-third the total energy required in an ethanol plant. The normal drum dryers were developed when energy was inexpensive. New types of dryers should be possible which are much more efficient and which would have application in other industries such as alfalfa dehydration.

- By-products utilization. Research related to utilizing by-products is very limited--particularly the use of stillage. Research is needed on preservation, handling equipment, animal acceptance and nutritional value. At the present time beverage distillers are selling stillage for much less than its theoretical nutritional value.

- Efficient use of ethanol as a fuel. Little research and development work has been done on the use of pure ethanol in either spark ignition or diesel engines. Ethanol which is produced and used on the farm will present many unsolved problems not encountered with gasohol. To achieve most efficient use of this excellent high-octane fuel will require modifications of spark ignition engines including ignition timing, compression ratios and manifold design. The use in diesel engines will require extensive modification of the engine or the development of cetane improvement compounds.

SUMMARY

II. SUITABILITY OF ETHANOL FOR FUEL

Alcohols have been evaluated and considered satisfactory as fuels for internal combustion engines since the early 1900's.

This chapter is essentially a detailed summary of research dealing with the use and its related constraints of ethanol and ethanol-blends as fuels for engines. The conclusions that may be drawn from that research include the following:

- For specific given compression ratios and optimum engine adjustments, the thermal efficiencies of petroleum-based fuels and ethanol and ethanol-based fuels are substantially similar.
- The power output of all such fuels is essentially proportional to the energy content of the fuel conveyed to the cylinder.
- The energy content of ethanol and ethanol-blended fuels is lower than that of petroleum-based fuels; therefore, specific fuel consumption is nearly always greater for ethanol and ethanol-blended fuels.

The potential application of ethanol to engine and other uses is summarized below.

Gasoline-Ethanol Mixtures in Spark Ignition Engines

The acceptable use of farm-produced ethanol in mixtures with gasoline is theoretically possible and since virtually no engine modifications would be necessary, the easy conversion to and from gasoline would be possible. However, the phase separation problem must be dealt with either through the use of 200 proof ethanol or by the addition of cosolvents or other additives; cosolvents have been found but are still too expensive.

Volumetric fuel economy from a 10 percent ethanol mixture will probably be reduced by about 2.5 percent, a condition indicating that ethanol replaces 75 percent of the gasoline heat value. Less tangible advantages of ethanol, however, appears to offset this factor in practices so that gasohol and straight gasoline can be assumed to have about the same volumetric efficiency.

Ethanol in Spark Ignition Engines

Ethanol use in spark ignition engines was evaluated by considering two specific cases, 1) carburetion and induction modifications, and 2) carburetion and induction modification plus an increased compression ratio.

Case 1 considers an engine with carburetion and induction modifications designed to allow operation with either ethanol or gasoline. Changes would require either adjustable or dual carburetors, additional intake manifold heat, a starting aid, and an easily adjusted ignition timing system. The compression ratio would remain standard (an assumed 8:1) to allow operation on gasoline.

The value of the 200 proof ethanol used in this application would be its energy value plus a 3 percent efficiency improvement (see Chapter II). Combining this with the data on efficiency versus proof results in:

Proof	Energy content 1/ (Btu)	Thermal efficiency relative to gasoline 2/	Volumetric value relative to gasoline
200	76,152	103	.67
190	72,344	94	.58
160	60,921	86	.45
120	45,691	81	.32

1/ No negative charge for latent heat of water.
2/ For reductions due to lower proofs see Table II-3.

No credit is given for high octane, since the compression ratio was not raised to take advantage of it.

Case 2 considers an engine with induction and carburetion changes plus the raising of the compression ratio from 8:1 to about 12:1. Starting aids are also needed. Such an engine could not be converted easily back to gasoline on a day-to-day basis.

The cost of such a conversion would vary greatly. For example, a high-compression, natural gas irrigation engine might require only minor head planing, a replacement carburetor, a fuel pump, and a tank, at a total cost under $700. Other engines might not have adequate head material for planing and could require high compression pistons to increase the total overhaul and conversion cost to $2,000 or more.

The value of ethanol in this application would be increased from that of Case 1, an effect of its increased compression ratio (CR), and engine efficiency. As Figure II-3 indicates, the ratio "Efficiency at 12:1/Efficiency at 8:1" equals roughly 1.13, producing:

Proof	Energy content (Btu)	Thermal efficiency relative to gasoline at 8:1 CR	Volumetric value relative to gasoline
200	76,152	116	.76
190	72,344	106	.66
160	60,921	97	.51
120	45,691	91	.36

Diesels Converted to High Compression Spark Ignition

Since spark ignition parts are not available for most currently used diesels, such components would have to be developed prior to the widespread retrofitting of existing engines. In addition, the costs of such a retrofit would be high and would discourage the conversion of older diesels.

A high-compression, spark ignition engine theoretically achieves 95 percent of the thermal efficiency of the diesel. Since this conversion adds a throttle plate and accompanying pumping losses at light loads, the previously proposed 3 percent efficiency advantage due to ignition advance is not applicable in this case. The value of the ethanol becomes:

Proof	Energy content (Btu)	Thermal efficiency relative to diesel at 17:1 CR	Volumetric value relative to No. 2 diesel
200	76,152	95	.52
190	72,344	87	.46
160	60,921	79	.35
120	45,691	75	.25

Ethanol in Diesels

Straight ethanol lies far, far outside most diesel engine manufacturers' fuel specifications (e.g. ethanol's cetane number is quite low) so the direct substitution of ethanol for diesel fuel cannot be seriously contemplated. Poor engine performance, knock, and severe engine damage are almost certain to occur as a result of such a substitution.

Additives to improve the cetane of ethanol are a distinct possibility, but the current costs and quantities required seem to discourage their use. A more probable long-term option would be the combination of moderate amounts of additives and revised multifuel engine design. While considerable development of this concept would be necessary and implementation would be slow, it merits consideration.

The value of ethanol in this application is not well documented, but multifuel research, in general, suggests an energy substitution. This leads to a value for 200 proof ethanol of .55 times that of diesel fuel.

Ethanol-Diesel Mixtures

Ethanol-diesel mixtures are subject to much the same difficulties as ethanol-gasoline mixtures; in addition, other problems inhibit their use. Phase separation is apparently at least as critical as with gasoline, and the lower energy content of ethanol is reflected as well. The major additional problem stems from the low cetane rating of ethanol, a condition which tends to increase the ignition delay and reduce efficiency at light loads.

Because of these difficulties, ethanol will have a value of somewhat less than its heating value when mixed with diesel fuels. Strait (1978) showed that at three-fourths load (considered average), thermal efficiency reductions varied from zero to 3 percent for a 30 percent ethanol blend. Thus, an average 1.5 percent thermal efficiency reduction for 30 percent blends is equivalent to an 8 percent reduction in the effective heating value of ethanol to give it a value of .51 times that of diesel fuel in this application.

Carbureting Ethanol into Diesels

The most feasible near-term technology for using ethanol in diesel engines is carburetion. Retrofit hardware is currently available in limited quantities, efficiency is equal to pure diesel operation, and the risk of engine damage appears low (provided the aspirated ethanol is used to replace diesel fuel rather than to boost power). The primary disadvantages of this approach are its conversion costs and the inconvenience of its separate fuel tanks.

The value of ethanol in this application will be estimated at its heat value, or:

Proof	Energy content (Btu)	Volumetric value relative to No. 2 diesel
200	76,152	.55
190	72,344	.52
160	60,921	.44
120	45,691	.33

Other Uses

Potentially, ethanol could serve as a substitute for other farmstead energy requirements, including grain drying and livestock confinement heating. For these purposes a lower proof ethanol would be satisfactory.

In order to use ethanol in crop dryers, their burners would require modification. The relative value of ethanol in grain drying compared to propane can be estimated based on the energy content of the two fuels. The energy that can be obtained from burning a gallon of propane is 81,855 Btu compared to the 76,152 Btu for ethanol. If substitution were strickly on a Btu basis, then 1.07 gallon of ethanol would be required to replace 1 gallon of propane.

If ethanol is to be substituted for fuel oil in the heating of buildings, their comparative energy content (76,152 Btu for ethanol; 138,690 Btu for fuel oil) indicates that 1.8 gallons of ethanol would be required to replace one gallon of fuel oil. The lower flash point of ethanol (55^{o}F) makes it less attractive than fuel oil for heating homes and commercial buildings.

II. SUITABILITY OF ETHANOL FOR FUEL

Alcohols have been evaluated as fuels for internal combustion engines since the early 1900's and have proven to be satisfactory although subject to constraints.

A. Basic Fuel Properties

The use of ethanol in agricultural engines is subject to a number of constraints that are a result of its basic properties. Thus, a comparison of ethanol to the more conventional sources of agriculture energy is in order. Table II-1 shows a few of the properties of gasoline, octane (which is often used for research purposes), propane (representing agricultural LPG), ethanol and diesel fuel (No. 1 and No. 2).

Both higher and lower heating values are shown in the table. Lower heating values assume that the water from combustion is exhausted in the gaseous state, a condition normally appropriate for engine usage. This is why the BTU value of anhydrous ethanol is reported at 76,152 throughout this report. However, since higher heating values are often quoted in the popular press, these are also tabulated for comparative purposes.

Conventional hydrocarbon fuels contain 18-20,000 Btu/lb, with the differences in "per gallon" figures resulting primarily from specific gravity variations. Ethanol contains substantially less energy per unit of weight than the conventional fuels. Compared to gasoline, ethanol contains about 61 percent as much energy per unit weight, or about 65 percent as much energy per unit volume. However, when compared to propane, ethanol contains 93 percent as much energy per unit volume.

Another key difference between ethanol and conventional fuels is the heat of vaporization. The conventional fuels require from 100 to 150 Btu in order to vaporize each pound of fuel, with gasoline reported at 142 Btu/lb. By contrast, ethanol requires 361 Btu/lb, or about 2.5 times as much energy per unit weight. When combined with the heat of combustion, it is apparent that ethanol requires nearly 4.2 times as much vaporization energy per unit of heat input as does gasoline. The implications of this will be discussed later.

Ethanol is a single compound fuel as opposed to gasoline and diesel fuel which contain a variety of compounds. As a result, ethanol boils at a specific temperature, rather than over a range of temperatures. The vapor pressure and flammability limits of the ethanol, combined with its high heat of vaporization, can cause starting problems in engines operated on straight ethanol.

Table II-1. Fuel Properties

	Gasoline	Octane	Propane	Ethanol	No. 1 Diesel	No. 2 Diesel
Chemical formula	--	C_8H_{18}	C_3H_8	C_2H_5OH	---	---
Molecular Weight	~126	114	44	46	~170	~184
Carbon % by Wt	--	84	82	52	---	---
Hydrogen % by Wt	--	16	18	13	---	---
Oxygen % by Wt	--	--	--	35	---	---
Heating Value						
Higher Btu/lb	20,260	20,590	21,646	12,800	19,240	19,110
Lower Btu/lb	18,900	19,100	19,916	11,500	18,250	18,000
Btu/gal (lower)	116,485	111,824	81,855	76,152	133,332	138,110
Latent Heat of Vaporization Btu/lb	142	141	147	361	115	105
Specific gravity	.739	.702	.493	.794	.876	.920
Research Octane	85-94	100	112	106	10-30	---
Motor Octane	77-86	100	97	89		
Cetane Number	10 to 20	--	--	-20 to 8	~ 45	---
Stoichiometric Mass A/F Ratio	14.7	15.1	--	9.0	--	---
Distillation Temperature (°F)	90-410	--	--	173	340-560	---
Flammability limits (volume percent)	1.4 to 7.6	--	--	4.3 to 19	--	---

Sources: Keller, J.L., et al., Use of Alcohol in Motor Gasoline--A Review, American Petroleum Institute, August 1971; Lichty, L.C., Combustion Engines Processes, McGraw-Hill, 1967; Taylor and Taylor, The Internal Combustion Engineer, International Textbook Company, 2nd Ed., 1966; Keller, J.L., Methanol and Ethanol Fuels for Modern Cars, Union Oil Company, presentation for World Federation of Engineering Organizations, November 1979; Freeman, J.H., et al., Alcohol in Tractors and Farm Engines, Agricultural Engineering, February 1941; Bandel, W., Problems in the Application of Ethanol As a Fuel for Utility Vehicles, International Symposium on Alcohol Fuel Technology, Methanol and Ethanol, November 21-23, 1977, Wolfsburg, Germany; Ethanol Production and Utilization for Fuel, Cooperative Extension Service, University of Nebraska, 1979.

B. Farm Fuel Usage and Engine Characteristics

The three basic fuels now in use in agricultural engines are gasoline, diesel fuel and liquified petroleum gas (LPG). The 1970 data (USDA-ERS, 1974) placed the average engine usage on U.S. farms (including transportation) of the three fuels at 18.6, 6.0, and 1.8 gallons per acre, respectively. However, when only farms over 500 acres were considered, the usage was estimated at 10.9, 7.9, and 2.3 gallons/acre, respectively.

The USDA conducted a detailed study of the energy used in farm production in 1974. Crop and livestock production operations used an average of 10.9 gallons of gasoline, 7.7 gallons of diesel fuel, and 4.3 gallons of LP gas per acre of cropland harvested (FEA/USDA, 1976). When only crop activities were considered the per acre inputs were 8.5 gallons of gasoline, 6.7 gallons of diesel fuel, and 3.4 gallons of LP gas. This study did not include fuel for farm household use.

More recent information (Schrock, 1980) indicates that roughly 90 percent of the volume of fuel used for performing farm-field operations in Kansas consists of disel fuel with gasoline and LPG filling the remainder.

Historically, there have been several shifts in tractor fuel types (Yahya, 1977). Prior to World War II, about 35 percent of the models of tractors tested at the Nebraska Tractor Test Laboratory operated on gasoline and the remainder on kerosene and distillate (all were spark ignition). Immediately after the war, gasoline model tractors accounted for nearly 70 percent of the tests, but diesel and LPG models began to increase. By 1956 (the peak year for LPG), 50 percent of the units tested were gasoline 34 percent diesel and 26 percent LPG. In 1975, 8 percent of the models tested were gasoline, and 92 percent were diesel.

Retail sales document a rapid shift to diesel farm machinery (Table II-2). In 1979, the USDA survey of farm production expenditures indicated that farmers purchased as much diesel fuel as gasoline for production purposes. The reasons for this shift included the efficiency and durability of the relatively low maintenance requirements of diesels and the comparatively low cost of diesel fuel over the period. In 1975 (Yahya, 1977) gasoline tractors tested at Nebraska averaged 23 percent efficiency (based on power take off horsepower) while diesels averaged 27.5 percent. Additionally, the total numbers of tractors on farms has declined gradually, since 1968, as agriculture uses fewer but larger machines. The number of tractors on farms as of January 1, 1979 was 4,350,000, the lowest number since 1955. However total tractor power on farms increased to an all time high of 243 million horsepower.

In 1978, the most popular tractor size was 130-140 hp, and no domestic major manufacturer has recently introduced diesel tractors in sizes less than 100 horsepower. Tractor engine rated speeds range from 1900 to 2800 rpm with 2000 to 2400 are the most common. Four hundred to 500 cubic inch displacements are common in the 100-175 horsepower range with up to 1500 cubic inch engines available in large atriculated 4-wheel drives. Engines above 110 horsepower are generally turbo-charged, and aftercoolers are used on the more heavily boosted diesels in order to reduce intake temperatures.

Table II-2. Farm machinery stocks and diesel as percent of sales of tractors and self-propelled combines

Year	Farm machinery stocks 1/		Diesel as % of sales 2/	
	Tractors	Self-propelled combines	Tractors	Self-propelled combines
	-------(thousands)--------			
1970	4,619	790	72	14
1973	4,518	701	86	50
1978	4,493	538	95	95

Sources: 1/ U.S. Department of Agriculture, Changes in Farm Production and Efficiency, 1978, Economics, Statistics and Cooperative Service, Statistical Bulletin No. 628, January 1980.

2/ U.S. Department of Agriculture, Economic Research Service, The U.S. Food and Fiber Sector: Energy Use and Outlook, Senate Committee on Agriculture and Forestry, 1974, Updated with Sales data from the Farm and Industrial Equipment Institute.

C. Ethanol in Spark Ignition Engines

While spark ignition (SI) engines have largely been replaced by diesels for use in the field, most rural highway vehicles are still gasoline powered. There are two fundamental ways in which ethanol can be used in SI engines: as a fuel mixture with gasoline and as ethanol alone. Since the engine performance, engine modifications, and usage problems are different for the two approaches, they will be discussed separately.

1. Gasoline-Ethanol Mixtures

The use of gasoline-ethanol mixtures is certainly not new (Lichty 1967, Taylor 1966, Lucke 1907). Investigations were reported in the 1910's and again in the 30's and 40's. Thus, there is a considerable history of research to be drawn upon in assessing the feasibility and properties of such mixtures.

Phase Separation

One of the key well-documented problems of gasoline-ethanol mixtures involves the phase separation of alcohol from gasoline in the presence of water (Keller 1979). Such a phase separation results in the alcohol-water mix settling to the bottom of a vehicle's gasoline tank (or carburetor) and an extremely lean mixture (on a heat basis) being fed to the engine. This engine is not running on the gasoline-alcohol mixture but on alcohol alone. In all probability the engine will malfunction. Some experimenters have reported no separation problems encountered when mixing 160-190 proof ethanol with gasoline, but in general these trials involved little or no storage time between mixing and consumption and involved mixtures with relatively high levels of agitation and ambient air temperatures (Woods 1979; Schroder 1979).

The water tolerance of an ethanol-gasoline blend depends on several factors (Keller 1979) including the ethanol's concentration and temperature, the presence of cosolvents, and the makeup of the gasoline. In one test, water tolerance of a 10 percent ethanol blend was increased from .36 to .6 percent by heating it from -20^{o}F to 50^{o}F. Likewise, increasing the aromatic content of the gasoline from 14 to 38 percent moved tolerance from .52 to .65 percent at 50^{o}F. The effects of cosolvents such as iso-butanol, n-butanol, amyl alcohol, and 2-ethyl hexyl alcohol have been investigated. The water tolerance of a 10 percent ethanol mix was improved from .6 to .98 percent at 50^{o}F by the addition of 3.2 percent n-butanol.

The phase separation problem is important in considering on-farm options since most current on-farm still designs produce less than 200 proof ethanol. Even if the azeotrope of 95.6 percent alcohol is attained, a 10 percent mixture of ethanol in completely dry gasoline would still contain .44 percent water in the mixture. At this concentration phase separation would be anticipated at lower temperatures.

Until satisfactory additives are developed to alleviate phase separation problems , mixing less than 200 proof ethanol with gasoline is impractical. Such additives, however, are under development and may be available on the market soon.

Heat Content

Since ethanol contains only two-thirds the energy of gasoline, a mixture of ethanol and gasoline contains proportionately less energy than the original gasoline. In most cases, mixture percentages are given as a volume percent, so the calculated lower heating values are given in Table II-3. The heat value of the mix is given in Btu/gal and Btu/lb, as determined by brake specific fuel consumption (pounds per brake horsepower-hour). A small volume increase in mixing is neglected (Scheller, 1977).

Octane

Due to the relatively high octane number of ethanol, mixtures have a higher octane than straight gasoline. In fact, the improvement in octane number is generally greater than what would be calculated using the values in Table II-1. The blending octane number of ethanol has been reported in the range of 128 to 136 for research octane and 95 to 112 for motor octane, when the ethanol is used in 10 percent blends (Keller, 1979). Older research, dealing with low octane gasoline, placed the blending motor octane number of ethanol at 123 to 170 (Barger, 1941). The end result of adding 10 percent ethanol to modern gasoline is typically a three-number increase in research octane and a two-number increase in motor octane (Brinkman, 1979).

Volatility

Ethanol is a single compound fuel which boils at 173^{o}F, while typically gasoline compounds boil at approximately 80-437^{o}F. The addition of the ethanol to typical gasoline causes a marked dip in the distillation curve in the lower temperature regions (Figure II-1). Similarly, Reid vapor pressure of gasoline is increased approximately 1 psi by the addition of 10 percent ethanol (Freeman, 1976). Such changes can be expected to aggravate problems with carburetor evaporation losses, hot driveability, and vapor lock (Courtney, 1979).

Driveability problems of alcohol blends were assessed by Brinkman et al. (1975). As expected, the carburetor mixture of fuel and air had a major influence on total weighted driveability demerits, and since the alcohol mixtures had a leaning effect on the engine, they decreased driveability accordingly. The conclusion of the tests was that driveability was a function of stoichiometry (the fuel-air ratio), and no additional problems associated with the volatility were reported. Volatility problems, like other associated with fuel alcohol are, can be solved by appropriate fuel and ignition system modifications and it is likely that future automotive engines will be so modified.

Efficiency

Fuel economy is perhaps the single most controversial aspect of the combustion of ethanol-gasoline mixtures. Reports are varied, with many articles in the popular press citing improved gas mileage (on a volumetric basis) in vehicles. While there is some basis for these claims in the results of one relatively uncontrolled study (Sheller, 1977), reports of small mileage reductions are more numerous.

Table II-3. Calculated heat of combustion for ethanol-gasoline mixtures

Volume % Ethanol	Btu/gal	Relative Btu/gal	Specific gravity	Btu/lb
0	116,485	100	.739	18,900
10	112,452	96.5	.745	18,099
20	108,418	93.1	.750	17,333
30	104,385	89.6	.756	16,556
100	76,152	65.4	.794	11,500

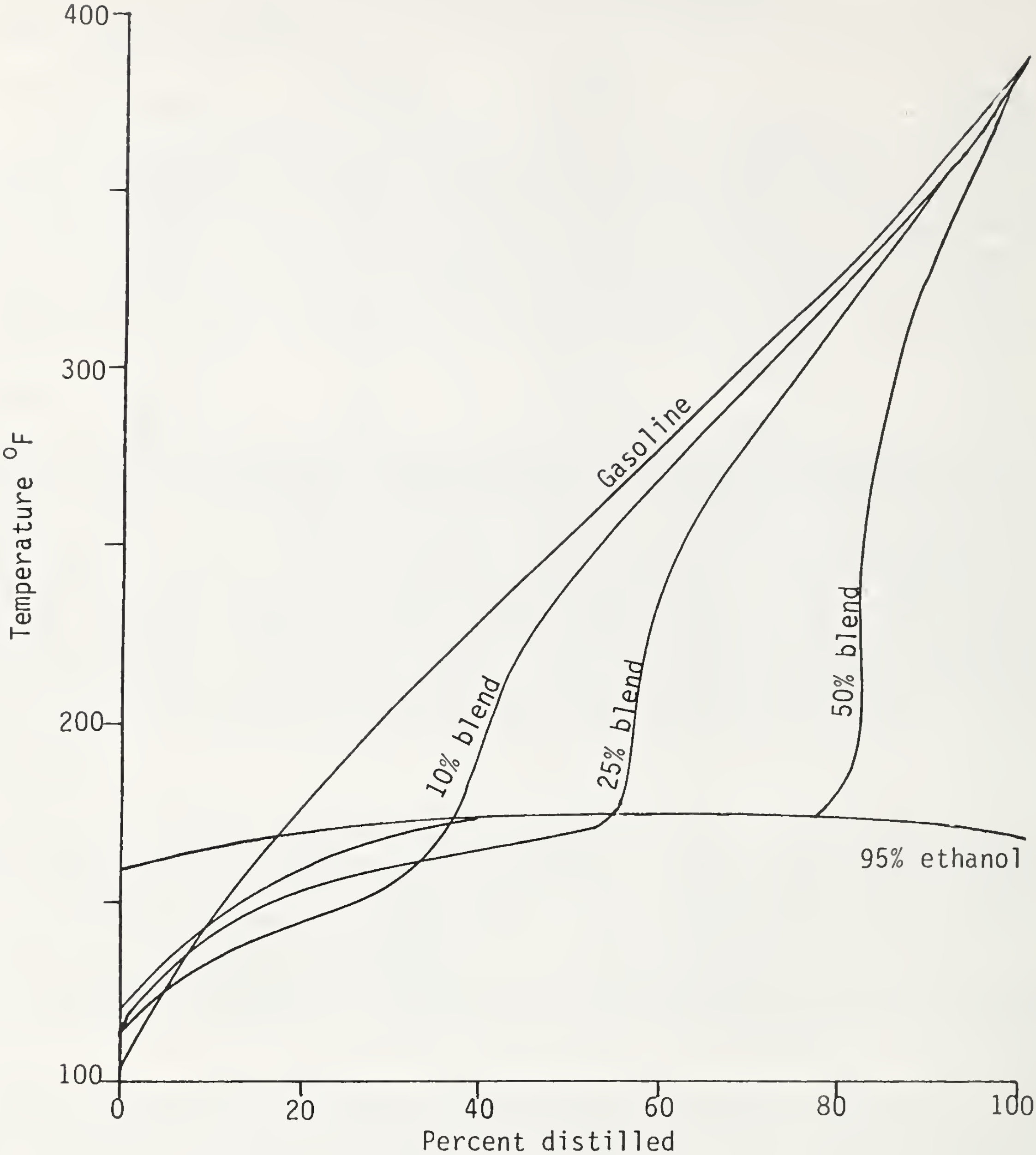


Figure II-1. ASTM distillation curves for gasoline, 95 percent ethanol, and various blends

Source: A. R. Rogowski and C. F. Taylor, J. Aeron. Sci. 8:384 (1941) as reprinted in Lichty, L. C. "Combustion Engines Process", McGraw-Hill, 1967.

The addition of ethanol affects fuel-air mixture and, therefore, motor efficiency. As mentioned previously, a 10 percent mix of ethanol will reduce the volumetric heat content by about 3.5 percent and result in leaning the mixture by a like amount. Since the main carburetor jets in nearly all vehicle carburetors are fixed and only the idle jets are adjustable, in normal vehicle usage, the owner of the vehicle will not enrich the carburetor when using ethanol-gasoline blends. However, older SI tractors normally are equipped with adjustable main jets and owners could manually enrich the mixture to allow the use of higher proportions of alcohol. In addition, some 1980 cars use a closed-loop feedback carburetor system (Automotive Engineering, 1979). This system utilizes an oxygen sensor in the exhaust manifold which provides a signal to a computer controlled electromechanical carburetor to control the mixture. Within limits, this system automatically compensates for variations in fuel and reduces the driveability problems caused by the leanness of ethanol mixtures. Such carburetion systems are almost certain to become more popular in the future.

The effects of mixture on efficiency of an SI engine are well documented (Taylor, 1966). Although the exact shapes and vertical position show some variation, the trends are usually similar to those shown in Figure II-2. That is, a minimum specific fuel consumption is usually evident at a fuel-air equivalence ratio of about .90-.95 (or slightly lean). Enriching the mixture further leaves unburned fuel, while leaning below the minimum brake specific fuel consumption (BSFC) point reduces flame speed and ultimately leads to lean misfire.

Tests on a 1973 model, 7.5 liter V-8 vehicle produced the results shown in Figure II-3 (Brinkman, 1975) expressed in terms of distance per unit energy, in volumetric fuel economy. As expected, the curves resemble the inverse of Figure II-2, with maximum mileage occurring at an equivalence ratio of about .95.

The effect of leaning the mixture by 3.5 percent (corresponding to a 10 percent ethanol mixture) depends on the initial mixture supplied by the carburetor. If the carburetion is relatively rich (i.e. equivalence ratio greater than .95) then the leaning increases the thermal efficiency of the engine. If the mixture is initially lean (equivalence ratio less than .95), then further leaning will reduce the thermal efficiency. This helps explain why some older cars that were carbureted rich may have shown an increase in fuel economy when operated on gasoline-ethanol mixtures.

In an effort to determine fuel economy on ethanol-gasoline blends, one study operated a vehicle at constant speeds as well as under highway, suburban, 1975 Federal Test Procedure, and business district cycles. Both standard and modified carburetion were used. Standard carburetion used an average air-fuel ratio of 15.7 and gave an equivalence ratio of .91 on the test gasoline and .88 on the ethanol-gasoline mixture. The results of the standard carburetion tests showed a reduction in thermal efficiency for the ethanol blend at speeds above 36 miles per hour, with roughly equal efficiency below that speed.

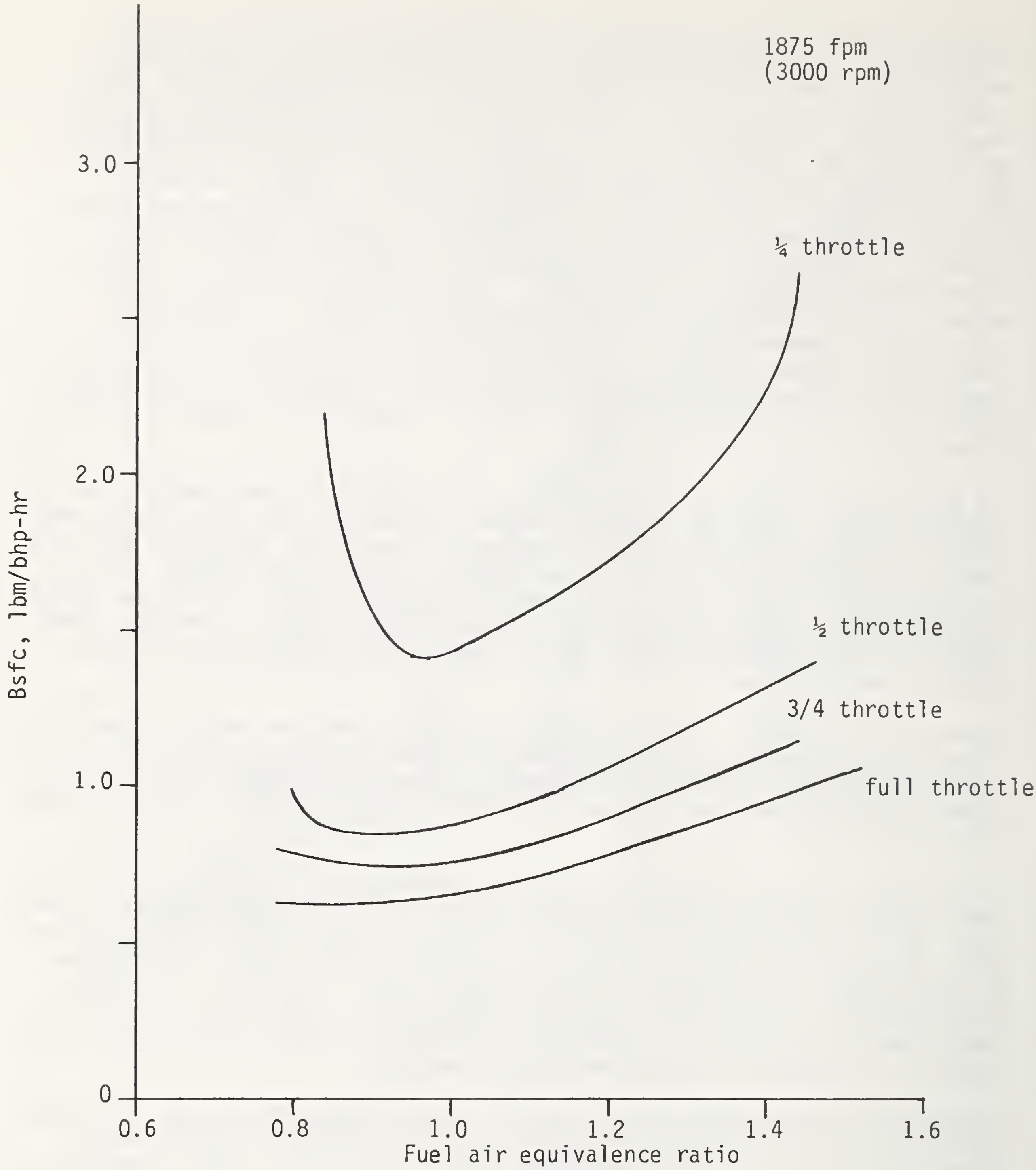


Figure II-2. Effect of fuel-air equivalence ratio on brake specific fuel consumption at various throttle settings.

Source: Taylor and Taylor, The Internal Combustion Engine, International Textbook Company, 2nd Ed. 1966.

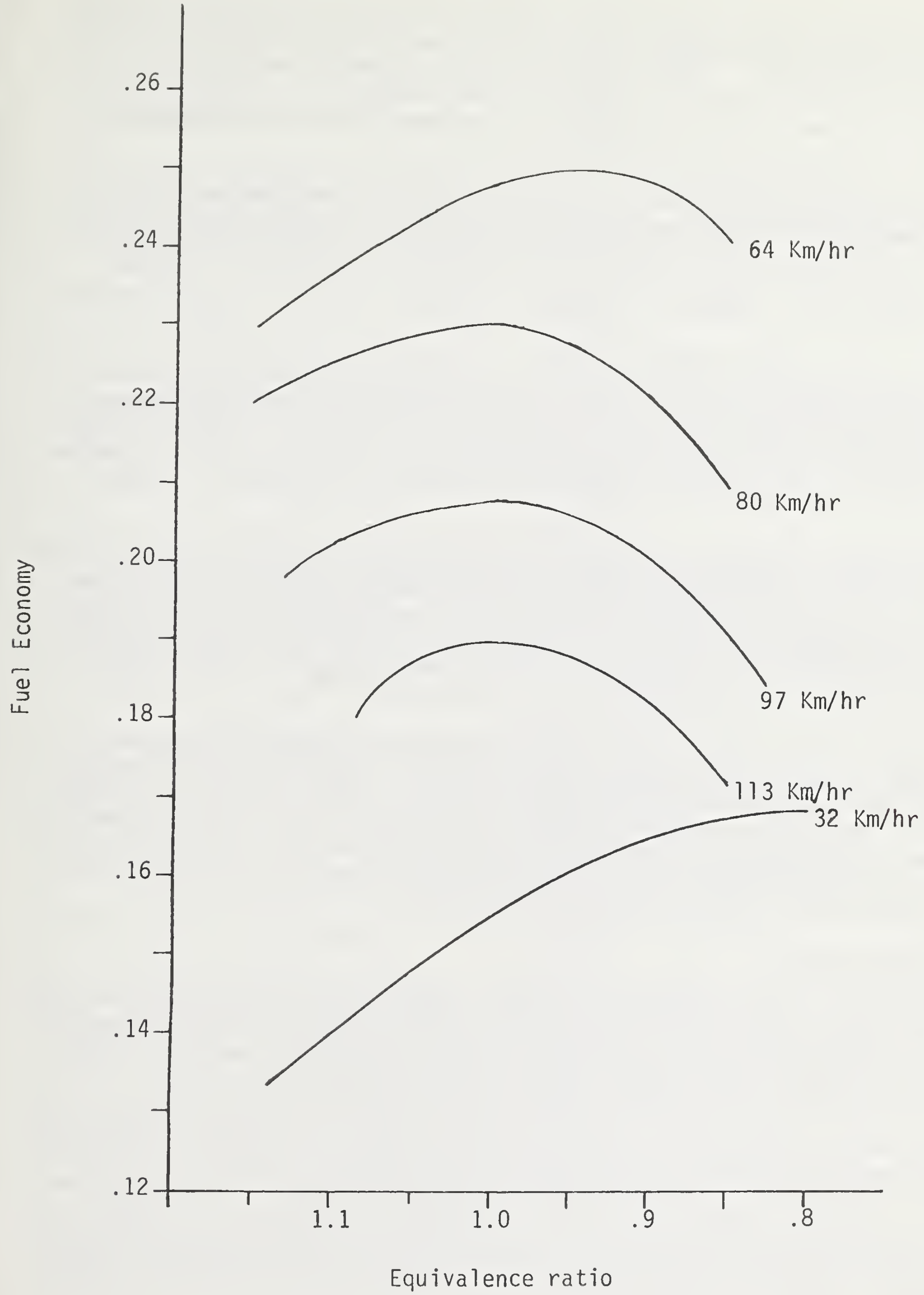


Figure II-3. Effects of alcohol and carburetion on level road load fuel economy (energy basis)

Source: Brinkman, N. D., Gallopoulos, N. E., and M. W. Jackson, Exhaust Emissions, Fuel Economy and Driveability of Volatiles Fueled with Alcohol-Gasoline Blends, SAE paper 750120, February, 1975.

The four test cycles were conducted at varying carburetor mixtures, and the results from ethanol blends generally fell on the same curves as the straight gasoline tests. Thus the overall conclusion of the study was that ethanol blends are equal to gasoline when compared on an energy basis (Brinkman, 1976) and represent roughly a 3 percent reduction in volumetric mileage.

Two Nebraska Gasohol test vehicles were tested at the ERDA Bartlesville Energy Research Center (Sheller, 1977). The two-car average showed a reduction in volumetric fuel economy when operated on a 10 percent ethanol blend. The reductions were 1 percent for the urban test and 3.1 percent for the highway test, figures in general agreement with those of Brinkman et al.

A more recent study involved a paired test of gasohol and gasoline-fueled cars at highway speeds. The cars were equipped for rapid fuel changes, and the remaining fuel in the car was weighed following each run. The results of the study were statistically significant at the 99 percent level, showing about 3 percent reduction in volumetric fuel mileage on gasohol (Kaufman, 1979).

Tests were made on a 1979 Toyota Supra equipped with a three-way catalyst and an oxygen-sensing, closed-loop feedback system (Pefley, 1979). The mixture compensating characteristics of this vehicle allowed operation on up to 50 percent ethanol while still meeting federal exhaust and evaporative emission standards. Volumetric fuel economy declined on the blends, while energy based fuel economy was unchanged.

These various fuel economy tests indicate that the mixture leaning caused by the addition of ethanol to gasoline will produce the greatest loss in volumetric gas mileage at highway speeds (Allsup, 1979). From a judgmental standpoint, volumetric gasoline mileage of an average vehicle will probably be reduced about 2.5 percent by a 10 percent ethanol blend. The octane enhancement from the alcohol is an advantage only if the blend is used in engines that need the added antiknock properties.

Engine Modifications

Although alcohol blends improve the octane number of gasolines, it is unlikely that farm vehicles will be modified (by raising compression ratio) to take advantage of the improved octane, since to do so would discourage the operation of the vehicle on the lower octane fuel available off the farm.

Presently, the operation of blends over approximately 20 percent ethanol may cause driveability and economy problems, particularly if the vehicle was originally carbureted lean. Carburetors could be re-jetted, but this (like modified compression ratio) would also compromise operation on straight gasoline, a condition solved only by the use of externally adjustable main jets (not commonly available) or by the installation of a dual carburetor intake manifold.

The mixture-associated driveability problems of alcohol-gasoline blends will become less of a factor with the anticipated widespread introduction of feedback carburetion on 1981 automobiles. By the same token, fuel

economy of blends will probably degenerate to coincide with their energy content even at lower highway speeds, since the feedback system would compensate for the slight leaning of the mixture.

2. Unblended Ethanol in Spark Ignition Engines

Considerable research and field experience information have been accumulated on the use of unblended ethanol in spark engines. The modifications associated with converting engines to ethanol are related to three general properties of ethanol.

Energy Content

As discussed previously (Table II-2), the volumetric heat content of ethanol is about two-thirds that of gasoline. Thus, the direct total substitution of ethanol for gasoline will produce such drastic mixture leaning that many engines will not run at all or will run very poorly (Doanes Agricultural Report, 1979). However, if exclusive alcohol operation is anticipated, the drilling of fixed jets can help alleviate these difficulties.

Mingle (1979) suggests that jet diameter should be increased by 27 percent when changing from gasoline to ethanol. However, another study (Duck, 1945), involving automobiles, suggests that more thorough modifications (including the enlargement of carburetor passageways) would be necessary in order to achieve proper mixtures over the required wide range of speed and load. If both gasoline and pure ethanol operations are desired, some form of adjustable jet or dual carburetion is necessary.

The amount of enrichment needed for ethanol may not be as much as would be expected, however, because of its ability to burn leaner (on a stoichiometric basis) than does gasoline. For example, one report (Freeman, 1976) placed the lean misfire limit of a test engine at 22 percent lean (from stoichiometric) for gasoline, but 36 percent percent lean for methanol. The report generalized a similar though somewhat leaner burn capability for ethanol.

Latent Heat of Vaporization

The high latent heat for ethanol is both an advantage and a disadvantage. On the positive side, the ethanol serves as a coolant and reduces intake temperature and improves volumetric efficiency. Furthermore, the increased likelihood of fuel being vaporized on the compression stroke tends to reduce compression work through lower temperatures and pressures (Obert, 1968). Both of these factors increase the performance of an engine, even when the compression ratio is fixed at gasoline levels. One study placed the power output for 95 percent ethanol (5 percent water) at 3 percent higher than for gasoline at the same compression ratio (Mueller, 1978).

The high heat of vaporization can cause mixture distribution problems in multi-cylinder carbureted engines. Most engines show cylinder-to-cylinder variations in mixture even with gasoline, and a later vaporizing fuel like ethanol maintains more liquid in the intake manifold and worsens the situation. One report found a maldistribution index of .06 for gasoline and .17

for methanol (ethanol was not tested) (Mueller, 1978). Potential cures for this problem are a) additional intake manifold heat from either water (Mingle, 1979) or exhaust, b) fuel injection to individual intake ports, or c) more careful manifold flow design to intensify higher mixture velocity and turbulence.

Perhaps the most noticeable effect of ethanol's low volatility is its cold starting. Saturated vapors are too lean to ignite below about 50°F (Keller, 1979), and starting problems become significant below about 40°F. Several cures are being developed. One study reports 1.5 minute start-ups on methanol at 25°F by using a 350 watt resistance heater in the manifold (Pefley, 1979). Conventional coolant heaters also have been used (Mingle, 1979). Another approach uses the addition of 5-10 percent gasoline to the alcohol (Mueller, 1978). Ether and acetone have also been tried, with 21 percent ether producing starts down to 0°F (Lichty, 1967). At any rate, some type of starting aid will be desirable for operation below a 40°F ambient temperature. Such aids are in common use with agricultural diesels, and the same general approach (commonly ether injection) may be a viable solution for alcohol fueled SI engines.

Octane

The high octane rating of ethanol presents an opportunity to improve the efficiency of most SI engines. If an engine is intended solely for ethanol operation, it can be modified internally to raise the compression ratio well above that for gasoline. One review (Bandel, 1977) suggested that for Brazilian gasoline, compression ratios of only about 7:1 are practical, while with ethanol, it is possible to raise the ratio to about 12:1. However, the relatively low speeds and high loads imposed by agricultural equipment use may dictate a practical limit somewhat below 12:1. For example, a common practice with engines using propane (which has an octane value above that of ethanol) was to use 8 to 10:1 compression ratios in farm tractor and irrigation engines.

Efficiency

Increasing an engines compression ratio also increases its thermal efficiency. This is particularly true at lower compression ratios, such as those used in older farm tractors. Figure II-4 shows the relative efficiency of ethanol, gasoline and diesel fuel as a function of compression ratio. The graph arbitrarily defines 18:1 compression ratio (CR) as 100 percent efficiency and compares the relative efficiency of other ratios to it. For example, an 8:1 compression ratio engine would extract about 84 percent as much work from each unit of heat input as would the diesel. Incidently this is in close agreement with the results of the Nebraska Tractor Tests as analyzed by Yahya. By operating an alcohol spark ignition engine at a 12:1 compression ratio, efficiency should be about 95 percent as high as diesel values (Bandel, 1977).

Other reports have suggested that additional factors improve the energy efficiency of ethanol combustion above what would be expected from compression ratio improvements alone. In one test, (Bernhardt, 1977) energy usage with ethanol was roughly 12 percent lower than with gasoline while power output was about 3 percent higher. Although compression ratio was constant in these tests, the fuel air ratio and ignition timing which were not reported may have been responsible for part of the variation. Another report (Mueller, 1978)

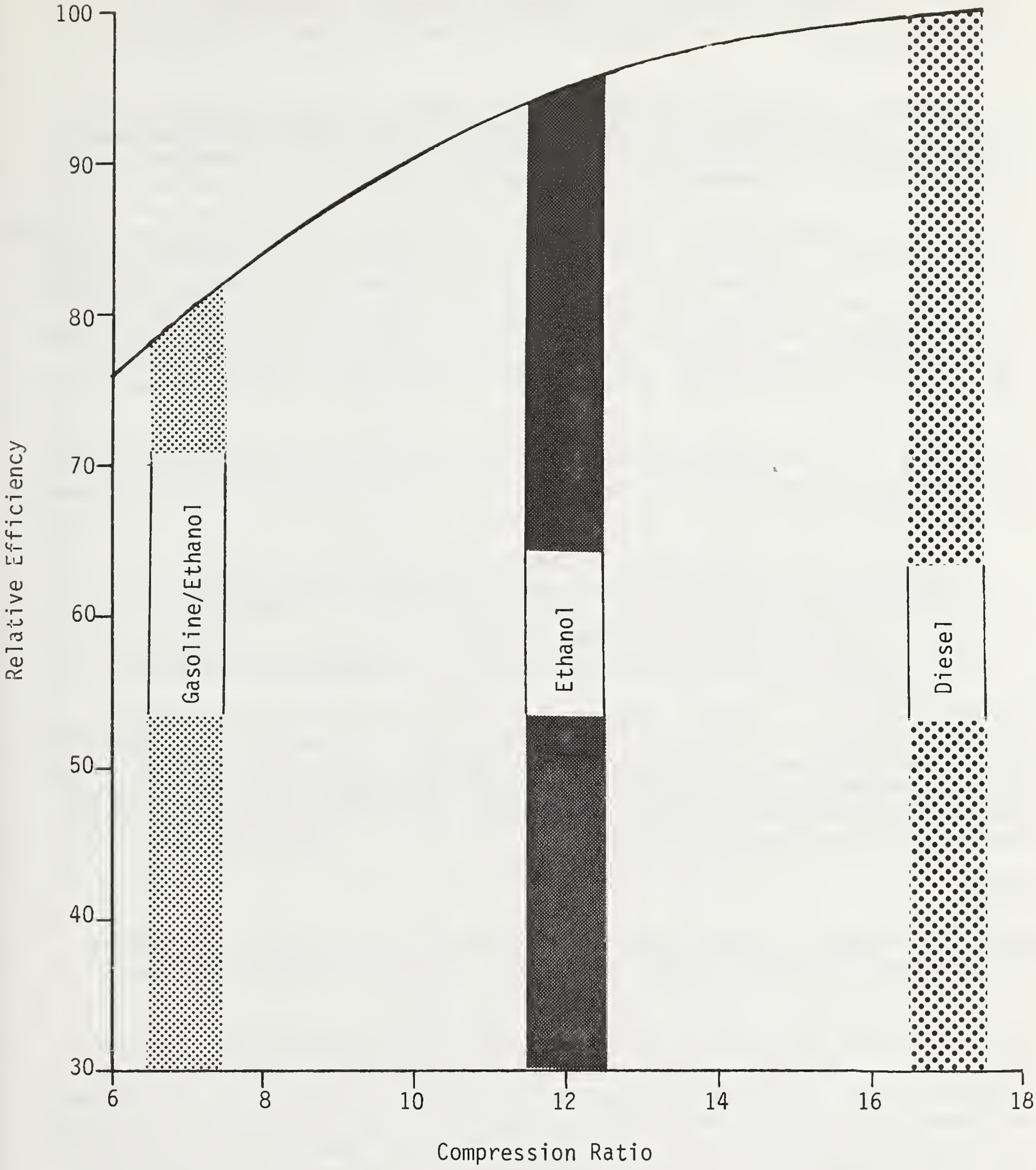


Figure II-4. Relative degree of effective force in relation to compression ratio

Source: Bandel, W., Problems in the Application of Ethanol as a Fuel for Utility Vehicles, International Symposium on Alcohol Fuel Technology-Methanol and Ethanol, November 21-23, 1977, Wolfsburg, Germany.

showed an increase from about 31.8 to 34.2 percent of indicated thermal efficiency by substituting methanol for gasoline (both fuels at stoichiometric mixtures).

The increased efficiencies of methanol have been attributed to these cooling effects on compression and to higher volumetric efficiencies (at wide open throttle) and slight increases in mole ratios (Obert, 1968). The same factors generally apply to a lesser extent for ethanol.

Although the improvements over gasoline in efficiency with methanol are apparent at full throttle operation, they are less obvious in the various emission certification cycles, since at part throttle the volumetric efficiency advantages of alcohols are largely lost. One report (Doanes Agricultural Report, 1979) placed methanol energy economy slightly above gasoline for both the urban and highway vehicle test cycles. Ethanol showed about equal energy economy on the urban test and about 10 percent poorer energy economy than gasoline on the highway test.

Thus there is not universal agreement in the test results comparing gasoline to ethanol at a constant compression ratio. The positive effects from ethanol can be summarized as:

- Intake cooling leading to higher volumetric efficiency
- Reduction in compression work due to internal cooling action
- Slight improvement in mole ratio of combustion (1.047 for gasoline vs. 1.065 for ethanol) (Freeman, 1976)
- Ability to burn at leaner (relative to stoichiometric) mixtures than gasoline.

The primary negative effect on engine efficiency of ethanol would be its poorer mixture distribution. In effect, then, comparative data imply that the positive factors outweight the negative and that the energy (Btu) efficiency of ethanol operations at a constant compression ratio will average about 3 percent better than gasoline operations.

Proof

Most of the engine research that has been reported in the literature deals with pure or 95 percent ethanol operations. Little information on lower (i.e. 120-180) proof research results is available.

One study (Duck, 1945) operated a 1942 Plymouth engine on ethanol from 200 proof down to 70 proof. The tests were conducted at full throttle, and both ignition timing and mixture were adjusted to achieve best power. No changes were made to the intake manifold heat supply, but spark plug wetting required installation of hotter plugs. Smooth operation was obtained down to 80 proof, but 70 proof resulted in inconsistent operation. During the 70 proof tests, one hour of operation raised the crankcase oil level by 6 to 8 quarts from its dilution by water and alcohol. The results are summarized in Table II-4.

The steady reduction in thermal efficiency for lower proofs stems, in part, from the latent heat of the water and the poorer mixture distribution.

Table II-4. Engine performance on low proof alcohol

Proof	Brake horsepower	Gal/hr blend	Ethanol lb/bhp-hr	Thermal efficiency1/	Optimum spark advance
200	47.67	6.85	.944	21.2	17.5
190	46.18	7.53	1.029	19.4	20.4
180	45.67	7.94	1.042	19.2	21.3
160	45.07	9.52	1.127	17.8	27.0
140	45.48	11.33	1.162	17.2	29.0
120	43.60	12.90	1.207	16.6	33.0
110	42.00	14.53	1.278	15.6	35.0
100	42.94	19.00	1.490	13.4	36.0
90	42.35	17.90	1.277	15.6	41.5
80	41.40	20.87	1.341	14.9	47.0
70	34.10	26.70	1.853	10.8	50.0

1/ Higher heating value used by this study (Duck, 1945) to calculate thermal efficiency.

Source: Duck, J. T. and Bruce, C. S., "Utilization of Non Petroleum Fuels in Automotive Engines". Natural Bureau Standards Journal Research 35:439 (1945).

A more basic problem of low-proof ethanol is its low energy density as compared with that of conventional hydrocarbons. For example, a fuel tank that would carry a vehicle 200 miles on gasoline would last about 135 miles with 200 proof ethanol, 95 miles with 160 proof ethanol, and 60 miles on 120 proof (Duck, 1945). For most farm machines (i.e. tractors, combines, etc.) the added weight and space occupied by an auxiliary tank are not crucial, but on conventional vehicles, it may be inconvenient and will reduce load capacity and lead to further reductions in fuel economy.

3. Materials Compatibility

Fuel systems in automobiles and farm machinery contain a number of different metal alloys and plastics, and several reports have mentioned difficulties from corrosion and chemical attack. However, the problems are generally perceived to be greater for methanol (and its blends) than for ethanol.

First, the solvent action of ethanol blends tends to loosen existing gum formations (and the rust they might hold) and deposit them in the fuel filters. This is most likely to occur just after the vehicle or storage tank is converted to ethanol storage and would tend to be a relatively short term problem (Keller, 1979).

Ethanol blends have led to the cracking of polyamide filter housings and to the degradation of polyurethane and polyester bonded fiberglass. When enough water is present to cause phase separation of ethanol blends, severe corrosion of steel and terne alloys (fuel tank material) has resulted (Keller, 1979). At least one small engine manufacturer has warned that gasohol (Spectrum, 1979) may cause corrosion in its engine.

Such incompatibility is apparently unpredictable, and some studies report no problems. Brazilian experience suggests that some new vehicle models (from countries not using ethanol mixtures) realize problems but that corrective action can be taken to "design in" ethanol compatibility (Mueller, 1978). Thus, it is reasonable to expect a certain amount of corrosion or chemical attack to occur in current U.S. produced vehicles and farm machinery if they are converted to ethanol or ethanol blends.

Wear

As with several other conditions previously mentioned, no clear consensus concerning the effects of ethanol or ethanol blends on engine wear is apparent. Nebraska work (Scheller, 1975) reported no unusual wear from a 10 percent ethanol mixture in vehicle operation, and work with alcohol-water injection (Wiebe, 1954) reported fewer deposits and less wear with the injection than without it.

In contrast, a more recent battery of tests using a Coordinating Lubricants Research engine in ASTM sequence II-C and V-C tests showed some negative results. The two test sequences approximated short-trip winter service and low-speed, low-temperature stop-and-go driving, respectively. Both denatured ethanol (BATF Formula 28A) and a 15 percent ethanol-gasoline mix were used. Ethanol showed a 180 percent increase in iron wear compared to that

for gasoline use and increased oil viscosity and acid content. The 15 percent mixture tests were inconclusive, and no lubricant effects were seen at the 240 hour point of the test (Owens, 1979).

Thus, it appears that at certain low temperature conditions, excessive cylinder wear can occur when straight ethanol is used. Work is continuing to better define the causes and extent of the problem, but it does not appear serious at higher engine temperatures.

Valve Recession

Following the switch to unleaded fuels in the late '60's and early '70's, many automobiles experienced a problem with rapid valve seat wear. The removal of tetraethyllead reduced the level of lubrication between the valve face and seat and the resulting softer seat eroded and allowed the valve to work deep into the head.

The problem was solved in the early 1970's by most manufacturers, mainly by induction hardening of the integral valve seats. However, vehicles produced before 1970 are still subject to the problem when operated for extended periods on unleaded fuels.

Since ethanol contains no tetraethyllead, its use in older cars may result in valve recession problems. The problem is serious when it occurs, often requiring head replacement or the installation of seat inserts.

Since spark ignition tractors were usually equipped with seat inserts, even the older models are unlikely to experience this problem.

D. Ethanol in Diesel Engines

Since diesel engines are the prime movers of agricultural field operations, it is important that any prospective farm produced fuel be adaptable to operation in diesels. Four basic approaches to using ethanol in a diesel have been mentioned:

- Converting the diesel to a high compression spark ignition engine
- Modifying the diesel to tolerate straight ethanol injection
- Mixing the ethanol with diesel fuel
- Carbureting the ethanol separately

Diesel engines operate on an entirely different combustion system than spark ignition engines. Diesel combustion is commonly divided into three phases (Taylor, 1966).

Ignition delay is the period between the start of injection and actual combustion. During the first part of this phase (or physical delay), fuel is atomized, vaporized, and mixed with air. Next, a preflame oxidation reaction occurs (called chemical delay) and is followed by the localized ignition

of the fuel. Since the total ignition delay time is less than the injection time, the first increments of fuel are made during ignition delay and additional fuel accumulates in the chamber.

Rapid Pressure Rise. Once ignition begins, the temperature and pressure in the chamber rises, a condition which shortens the ignition delay of the accumulated fuel. This causes a very rapid pressure rise and produces high stresses, the source of the well-known diesel "knock." Higher cetane fuels generally reduce the ignition delay and, thereby, control the rate of pressure rise within the combustion chamber. (Cetane rating measures the ease of self-ignition--a desirable property for diesel fuels.)

Controlled Pressure Rise occurs after the initial "pooled" fuel has burned, and combustion then continues to develop roughly at the rate of fuel injection.

For fuels in general, the autoignition properties that are desirable in a spark ignition engine are highly undesirable in a diesel. The octane rating system measures a fuel's resistance to self ignition, while cetane rating measures the ease of self-ignition. Fuels that have a high octane number (ON) have a low cetane number (CN), the approximate relationship (Cummings, 1977) being:

$$CN = \frac{104-ON}{2.75}$$

where: CN = cetane number
ON = octane number

Injecting a high octane fuel into a diesel can, therefore, be expected to produce a long ignition delay, followed by a very rapid pressure rise. The accompanying knock and stresses may be objectionable from the standpoint of both noise and engine life.

1. Converting Methods

Most current production diesel tractors operate with compression ratios of between 14 and 19 to 1. As such, they usually feature robust construction in the block, crank, and rods, so a diesel might seem to be an ideal candidate for conversion to high compression ethanol operation. However, since only a few current agricultural engines are now built in both spark ignition and diesel configurations, a ready source of spark ignition heads, manifolds, pistons, etc. is simply not available for most models.

One engine for which such parts are available is the 855 Cummins Diesel. This basic engine is currently being used in five models of four-wheel drive tractors, and it is also built in spark ignition natural gas configuration. The cost of conversion from diesel to natural gas varies with the initial condition of the diesel, but a minimum net conversion cost is about $3,000. Conversion to ethanol would be very similar to that for natural gas conversion. It would require the following new or replacement parts:

- Pistons
- Head Assembly
- Intake and Exhaust Manifolds
- Ignition System
- Carburetor
- Governor

Another approach to conversion has been mentioned (Kirik, 1979) and would involve installing a spacer to raise the diesel head and reduce compression to about 12:1. The diesel head would be drilled and sleeved to allow the installation of a spark plug. Ethanol would be injected through the diesel injectors, but timing would be advanced so that vaporization would take place during the compression stroke. A few potential problems of this system are that:

- the spacer would require careful machining to insure that combustion seal as well as oil and water flow would be maintained,
- the resulting combustion chamber would not be of ideal configuration,
- longer push rods and head bolts would be needed,
- drilling and sleeving a diesel head would probably compromise the spark plug location, structurally weaken the head, and present sealing problems,
- a throttle plate (synchronized with the injector pump) would be needed to maintain fuel to air ratios at light loads,
- cylinder wash down may result from the injection of the ethanol during the compression stroke, and
- injector pump lubrication may not be adequate without adding oils to the ethanol.

In essence, then, the problems suggest that this alternative will not achieve a satisfactory level of performance and durability.

2. Unblended Ethanol

Like gasoline and other low cetane fuels, ethanol is poorly adapted for direct use in diesels. Its use would require modifying the engine for enhanced multi-fuel capability and adding cetane improvers to the ethanol to improve its self ignition properties.

Engine Modification

Bandel (1977) suggested that a compression ratio of 25:1 in a direct injection diesel permitted full-load operation on ethanol and that part-load operation and starting on ethanol were not possible. For light-load operation, additional heat was applied to the intake by way of exhaust gas recirculation. This enabled light-load operation, but peak pressure and the rate of pressure rise were "far above" those of the original diesel design. Timing was retarded with the hope of reducing the rates of pressure rise, but it was thought that redesign with more rigid construction would be needed. Since exhaust gas recirculation would not ease starting difficulties, an additional modification would be necessary. The most practical solution would be to start the engine on diesel fuel and change to alcohol.

Some multifuel engines, developed for the military, use similar techniques to achieve satisfactory operation on fuels ranging from No. 2 Diesel (spec VVF-800) to combat gasoline (MIL-F-3056) (Obert, 1968). However, ethanol is higher octane (and lower cetane) than gasoline, so it would lie considerably outside the "multifuel" design range. When GM diesels are provided in multifuel configuration, the compression ratio is raised to 23:1, and modified injectors are installed to compensate for the higher volatility of gasoline.

The MAN diesel (also known as the Meurer, M, or Whisper diesel) is a unique combustion chamber designed for smooth operation. As such, it can tolerate relatively low cetane fuels without excessive combustion noise. It accomplishes this by injecting a coarse fuel spray that impinges on the inside of a spherical piston cup. The high swirl then controls the rate at which the fuel is heated and leads to a lower rate of pressure rise. With a compression ratio of 19:1, MAN diesels have been operated on 80 octane gasoline with no apparent combustion noise (Obert, 1968). Additionally, the MAN would seem to be the most alcohol tolerant of all the current diesel designs. However, multifuel capability has not been a design goal in agricultural equipment, and apparently only two manufacturers (IH and White) have offered MAN diesels in the agricultural market during the last ten years, and then only for relatively short periods.

The multifuel concept has considerable appeal, since one engine fuel system could theoretically suffice for diesel, gasoline, and ethanol. However, rack adjustments would be necessary when changing fuels because of a) the lower volumetric heat content of gasoline and alcohol, b) the increased leakage past the pump, and c) the lower bulk modulus of gasoline and alcohol (Obert, 1968).

Ethanol Modification

The second means of using ethanol directly in diesels is to improve the cetane number of the ethanol. Several compounds may be used for this purpose, but amyl nitrate seems most popular in the U.S. and cyclohexanol nitrate, in Europe. One study of cyclohexanol nitrate (Bandel, 1977) found that 10 percent of the additive in ethanol improved the ethanol to a par with diesel fuel and required no major engine combustion modifications. Of course, the fuel setting was increased for the above-mentioned reasons, but the thermal efficiency was unchanged from that of diesel fuel operation. The cost of this specific additive is not readily available, but a related study reported that 20 percent of a similar additive was uneconomic. Amyl nitrate raises the cetane of hydrocarbon fuel about 15 points when used at a 1.5 percent additive level (Obert, 1968). However, no reports documenting its performance when added to ethanol have been found.

From the standpoint of ethanol usage in the short term, the direct injection of ethanol in diesels offers little potential for the following reasons:

- Multifuel engines are not used to any great extent in agriculture.

- Kits to convert agricultural engines to multifuel combustion systems are not available, and retrofit conversion would be expensive.
- The probability of economical cetane improvement to allow ethanol use in conventional diesel combustion systems appears low.

In a longer term, the direct substitution of ethanol in diesels is perhaps the most practical for agricultural machinery. The following two elements appear to be necessary:

- The MAN system could be developed for multifuel agricultural usage. The combustion system has already been produced for diesel-only use in agriculture, so it follows that production costs of the system itself must not be excessive. Additional changes to improve performance with ethanol would include installing a multifuel injector pump and pressurizing the fuel to avoid vapor blockage of the pump.

- If cetane improvers act on ethanol similarly to their action on hydrocarbons, the values in the following table can be calculated:

Theoretical Values of Octane and Cetane for Ethanol With Additives*

Fuel	$\frac{R+M}{2}$ Octane	Calculated Cetane
Ethanol	97.5	2
Ethanol + 1 percent Amyl Nitrate	68	13
Ethanol + 2 percent Amyl Nitrate	46	21
Ethanol + 3 percent Amyl Nitrate	33	26

* Calculated from cetane enhancement values (Lichty, 1967) and cetane-octane conversion formula (Cummings, 1977).

Since MAN (or other multifuel) combustion with 80 octane fuel has been achieved, it appears that an economic compromise may be reached by using multifuel engine technology in addition to small amounts of cetane improvers in ethanol. This approach would have the added benefit of allowing a rapid conversion back to diesel fuel, using only revised rack settings and, perhaps, injection timing.

3. Ethanol and Diesel Fuel

The blending of ethanol, especially in low amounts--10 to 40 percent, with diesel fuel has been studied by several researchers.

The phase separation problem, discussed under spark ignition engines, apparently becomes even more critical when diesel fuel is used as the base. For example, one study found that at $32^{o}F$, only .05 percent water could be tolerated by ethanol-diesel blends at the 10 to 30 percent ethanol level. At $70^{o}F$, the 10, 20 and 30 percent blends would tolerate .13, .20, and .27 percent water, respectively (Strait, 1978). Thus, it is apparent that azeotropic ethanol (95.6 percent alcohol-4.4 percent water) would separate from diesel fuel at normal operating temperatures and that anhydrous ethanol would be desirable for diesel-ethanol mixtures.

Changes in distillation curves are far more marked for diesel-ethanol mixtures than for gasoline-ethanol mixtures. The 5 percent recovery point falls at about 380°F for No. 1 diesel fuel and at about 180°F for a 10 percent ethanol blend. Essentially, the ethanol evaporates at 170-180°, after which the remaining diesel fuel heats to 350-400° before continuing the curve (Strait, 1978). The drastic changes in distillation properties suggest that high evaporation losses in storage, as well as vapor lock and the cavitation of the injector pump, might be expected. Both of these problems were experienced in another study (Wrage, 1979) which found that it was necessary to store the ethanol-diesel blends in sealed containers to avoid ethanol evaporation. In addition, both chilling the blend and pressurizing it were investigated as ways to prevent stoppages caused by vaporization in the injector pump.

Strait et al.(1978) tested ethanol diesel mixtures in unmodified tractor engines. A 1962, 173 cubic inch Ford diesel and a 1978, 219 cubic inch John Deere were used. Both were direct injection designs with 16.8:1 compression ratio and operated at 1800 and 2000 rpm, respectively. The performance for both engines was similar. For the Ford, brake specific fuel consumption on blends was increased, reflecting the lower heat content of the ethanol. The increase in fuel consumption was greatest at light (one-fourth) loads when the reduced cetane number of the blends markedly increased ignition delay. Brake thermal efficiency was essentially unchanged for ethanol concentrations up to 30 percent at full and three-fourths load, while at one-fourth load, efficiency decreased exponentially at over 15 percent ethanol. The John Deere engine showed a similar loss in thermal efficiency at both one-fourth and one-half load.

For both engines, increased noise was apparent even at the 10 percent ethanol levels, while at 30 percent mixtures, both engines were "extremely noisy." Additional combustion studies showed a definite delay in ignition with the blends, especially at light loads. The peak cylinder pressures were also higher with the blends.

Another study (Bailey, 1979) ran diesel-ethanol blends in both a GM-3-53 and a military LD-465-1 (multifuel) diesel. Blends containing from 20 to 45 percent ethanol were tested, and a commercial additive was used to form the 45 percent emulsion. With the 30 percent ethanol blend, power was reduced from 5 to 18 percent, depending on engine speed. Efficiency was measured in terms of relative vehicle range, a volumetric (not energy) basis. Again, with the 30 percent blend, range was reduced from 3 to 13 percent depending on speed.

At any rate the key problems with ethanol-diesel blends in unmodified diesels appear to be:

- the water sensitivity of the blends, which requires anhydrous ethanol,
- the modified distillation curves, requiring fuel pressurization on some tractor models, and
- the reduced cetane number and energy content of the blends, leading to concerns about cylinder pressures and engine life.

Most current diesel injection pumps are lubricated by the diesel fuel that they supply to the engine. This and the lower viscosity of ethanol compared to diesel fuel cause concern for injector pump lubrication and life.

As part of a recent diesel fuel screening project (Bailey, 1979), bench tests were conducted to determine the friction and wear characteristics of various substitute fuels. Conducted in accordance with ASTM method D2714-68, the tests measured the coefficient of friction as well as the width of the wear track on a standard test block. The table shows the results for diesel fuel, unleaded gasoline, ethanol, and an 80 percent gasoline - 20 percent diesel fuel mixture.

Fuel	Average wear track width (MM)	Maximum observed friction coefficient
Diesel fuel	1.17	.15
80% gasoline - 20% diesel	1.32	.18
Ethanol	1.58	.27
Gasoline	1.99	.45

Although the lubrication performance of ethanol was somewhat poorer than that of diesel fuel, it is superior to gasoline's. Also of interest is the substantial improvement of gasoline's lubrication performance with the addition of 20 percent diesel fuel. No ethanol-diesel blends were tested, but if a similar improvement occurs, potential injector pump lubrication problems should be greatly reduced by the addition of even small amounts of diesel fuel to the ethanol.

4. Carbureted Ethanol

Carbureting (or "aspirating," or "fumigating") spark ignition type fuels into diesel engines has been practiced for many years using fuels such as natural gas, LP gas, and gasoline. In some cases, the object was to reduce diesel smoke emissions and in others more power and multifuel operation were sought.

Of the four options for using ethanol in diesels, this concept is currently receiving the most popular attention, due in large part to the availability of a conversion kit sold by the M&W Gear Company, Gibson City, Illinois. The device introduces 100 proof ethanol (or methanol) into the engines air intake just upstream from the turbocharger. It uses the turbo boost pressure to pressurize the alcohol tank and, thereby, meter the alcohol as a function of engine load. Ethanol is not added at light loads. Advertising literature (Meiners, 1979) states that in company tests, the device reduced the tractor diesel fuel consumption from 8 1/2 gallons per hour to 6 gallons per hour while adding 2 gallons of 100 proof ethanol. The tractor produced 125 horsepower in both cases, so in the pure diesel test, thermal efficiency was 27.1 percent. With the alcohol injection, the reported figures would correspond to a thermal efficiency of 35.2 percent.

Alcohol fumigation tests date from the early 1950's (Panchapakisan, 1977). In general, tests have shown alcohol fumigation leads to poorer thermal efficiency at light loads and better thermal efficiency at overload. Fumigation is better adapted to direct injection, open-chamber engines.

The reduction in efficiency at part load was thought to be caused by the increased ignition delay brought on by the alcohol fumigation. The combustion was highly subject to the ratio of diesel flow to alcohol flow, and at 30 percent of maximum diesel flow, only a small amount of alcohol could be burned before the engine began missing. Ignition delay with 40 percent of maximum diesel flow was 43.5°; with 75 percent of maximum diesel flow, the delay was about 33°.

The increase in thermal efficiency at high loads is apparently due to the better air utilization from the fumigation. The results of pure diesel and 75 percent of maximum diesel flow tests are summarized below:

Thermal efficiency of a single cylinder test enginer at 1500 RPM

Horsepower	Thermal efficiency pure diesel	Thermal efficiency 75% diesel flow remainder ethanol
5	31 percent	31 percent
6	31 percent	33 percent
7	25 percent	33 percent

It is apparent that at overfueled conditions (when the thermal efficiency of a conventional diesel decreases), a comparable amount of power can be obtained by using fumigation while maintaining a high level of thermal efficiency (Panchapakesan, 1977). Under such conditions, peak cylinder pressures were about the same, but the rate of pressure rise was higher for the alcohol fumigation.

The tests also concluded that the advancement of injection timing would in part compensate for the increased ignition delay and allow higher levels of alcohol use. In one test, 80 percent of the total heat input was supplied by ethanol (Panchapakesan, 1977). Since the no-load diesel fuel flow was about 30 percent of the maximum flow, the proposed concept was that diesel flow be kept at no-load flow and that the amount of carbureted alcohol would control the engine's response to load. High rates of pressure rise were deemed unacceptable in some cases, and work on the concept is continuing.

A similar study, one using a special direct injection diesel with a single hole injector to study pilot injection concepts, found that a minimum of 30 percent of the heat energy should be supplied by the pilot (diesel) fuel. The study reported a strong increase in thermal efficiency (from 14.7 to 19.9 percent at the 1.61 kw reference condition), a condition again thought to be due to improved air utilization (Bro, 1977). It should be commented that the single hole injector used in this study is not representative of normal practice and may have been responsible for the rather low efficiencies of the straight diesel operation. It was also apparent from this study that the air-ethanol ratio must be held below certain levels to avoid the lean misfire of the bulk gases.

Barnes (1975) reported on a system remarkably similar to that utilizing the M&W conversion kit. A pressurized alcohol tank and nozzle was added to the test engine--an Oliver F-310-DBLT--a turbocharged 6 cylinder unit used in the model 1855 tractor. Alcohol was introduced upstream of the turbocharger, and it served as an effective charge coolant to lower intake temperature by 70°F when the ratio "mass alcohol/mass diesel fuel" (denoted as "A") reached 1.0 during full load tests.

Changes in brake thermal efficiency from adding the ethanol at full load were negligible, with all points falling between 34 and 35 percent (Barnes, 1975). "A" was varied between 0 and 1.2 in the tests. However, full load runs using isopropanol showed a gradual increase from 35 percent to about 37.5 percent thermal efficiency as "A" increased from 0 to 1.0.

Light loads were tested only with methanol, and at 33 percent load, thermal efficiency decreased from 36 percent to 29 percent as more alcohol was added (again varying "A" between 0 and 1.0). The poorer fuel economy with alcohol at light loads was thought to be due to incomplete vaporization by the turbocharger. At "A" of 1.0 and 33 percent load, methanol dripped from the turbocharger housing.

In the final analysis, it appears that ethanol fumigation can improve thermal efficiency under certain conditions, specifically, if an overfueled condition exists while using straight diesel fuel, a comparable amount of power can be obtained at higher efficiency by reducing the amount of diesel fuel injected and replacing it with fumigated ethanol. The homogeneous nature of the air-ethanol mixture is believed to improve air utilization of the diesel, but one study suggests that the air-alcohol ratio must still be maintained below a certain level in order to avoid the incomplete burning of the alcohol (Bro, 1977). Ethanol fumigation seems relatively ineffective at engine loads below 50 percent, but at higher loads, a fairly large proportion of total energy can be supplied by the ethanol. As loads increase, some additional diesel fuel must be used. We estimated that, on the average, alcohol could replace 30 percent of the diesel fuel by volume.

Overfueling is generally not present in standard farm tractors, as evidenced by the fact that full load efficiency is almost always higher than 75 percent load fuel efficiency (Leviticus, 1979). Thus, as a general practice for farm tractors, ethanol fumigation will not be credited with an improvement in efficiency but should be valued on a heat content basis. In one review (Strait, 1978) it is mentioned that lower proof ethanol also produced no improvement in thermal efficiency over 200 proof, therefore low proofs should also be valued on a heat content basis.

E. Applications

1. Engine Use

Gasoline-Ethanol Mixtures in Spark Ignition Engines

The acceptable use of farm-produced ethanol in mixtures with gasoline is feasible and since virtually no engine modifications would be necessary, easy conversion to and from gasoline would be possible. However, the phase separation problem must be dealt with either through the use of 200 proof ethanol or by the addition of cosolvents and other additives.

As discussed previously, volumetric fuel economy from a 10 percent ethanol mixture will probably be reduced by about 2.5 percent, a condition that indicates that ethanol replaces 75 percent of the gasoline heat value.

Ethanol in Spark Ignition Engines

Case 1 will consider an engine with carburetion and induction modifications designed to allow operation with either ethanol or gasoline. Changes would require either an adjustable carburetor or dual carburetors, additional intake manifold heat, a starting aid, and an easily adjusted ignition timing system. However, the compression ratio would remain standard (an assumed 8:1) to allow operation on gasoline.

The value of 200 proof ethanol used in this application would be its energy value plus a 3 percent efficiency improvement due to factors discussed previously. Combining this with the data on efficiency versus proof results in:

Proof	Energy content 1/	Thermal efficiency relative to gasoline 2/	Volumetric value relative to gasoline
200	76,152	103	.67
190	72,344	94	.58
160	60,921	86	.45
120	45,691	81	.32

1/ No negative charge for latent heat of water.

2/ For reductions due to lower proof see Table II-3.

Notice that no credit is given for high octane, since the compression ratio was not raised to take advantage of it.

Case 2 considers an engine with induction and carburetion changes plus the raising of compression ratio from 8:1 to about 12:1. Starting aids are also needed. Such an engine could not be converted easily back to gasoline on a day-to-day basis.

The cost of such a conversion would vary greatly. For example, a high-compression, natural gas irrigation engine might require only minor head planing, a replacement carburetor, a fuel pump, and a tank, at a total cost under $700. Other engines might not have adequate head material for planing and could require high compression pistons to increase the total overhaul and conversion cost to $2,000 or more.

The value of ethanol in this application would be increased from case 1 in proportion to the engine efficiency due to its increased compression ratio (CR). From Figure II-3, the ratio "Efficiency at 12:1/Efficiency at 8:1" equals roughly 1.13, producing:

Proof	Energy content	Thermal efficiency relative to gasoline at 8:1 CR	Volumetric value relative to gasoline
200	76,152	116	.76
190	72,344	106	.66
160	60,921	97	.51
120	45,691	91	.36

Diesels Converted to High Compression Spark Ignition

Since spark ignition parts are not available for most currently used diesels, such components would have to be developed prior to the widespread retrofitting of existing engines. In addition, the costs of such a retrofit would be high and would discourage the conversion of older diesels.

According to Figure II-4, a high compression spark ignition ethanol engine theoretically achieves 95 percent of the thermal efficiency of the diesel. Since this conversion adds a throttle plate and accompanying pumping losses at light loads, the previously proposed 3 percent efficiency advantage due to ignition advance are not applied in this case. The value of the ethanol becomes:

Proof	Energy content	Thermal efficiency relative to diesel at 17:1 CR	Volumetric value relative to No. 2 diesel
200	76,152	95	.52
190	72,344	87	.46
160	60,921	79	.35
120	45,691	75	.25

Ethanol in Diesels

Straight ethanol lies far, far outside most diesel engine manufacturers' fuel specifications, so the direct substitution of ethanol for diesel fuel cannot be seriously contemplated. Poor engine performance, knock, and severe engine damage are almost certain to occur as a result of such a substitution.

Additives to improve the cetane of ethanol are a distinct possibility, but the current costs and quantities required seem to discourage their use. A more probably long-term option would seem to be the combination of moderate amounts of additives and revised multifuel engine design. While considerable development of this concept would be necessary and implementation would be slow, it merits consideration.

The value of ethanol in this application is not well documented, but multi-fuel research in general suggests an energy substitution. This leads to a value of 200 proof ethanol of .55 times that of diesel fuel.

Ethanol-Diesel Mixtures

Ethanol-diesel mixtures are subject to much the same difficulties as ethanol-gasoline mixtures, plus some additional problems. Phase separation is apparently at least as critical as with gasoline, and the lower energy content of ethanol is reflected as well. The major additional problem stems from the low cetane rating of ethanol, a condition which tends to increase the ignition delay and reduce efficiency at light loads.

Because of these difficulties, ethanol will have a value of somewhat less than its heating value when used in this application. Strait (1978) showed that at three-fourths load (considered an average), thermal efficiency reductions varied from zero to 3 percent for a 30 percent ethanol blend. Thus, an average 1.5 percent thermal efficiency reduction for 30 percent blends is equivalent to an 8 percent reduction in the effective heating value of ethanol, giving it a value of .51 times that of diesel fuel in this application.

Carbureting Ethanol Into Diesels

This approach appears the most feasible near-term technology for using ethanol in diesel engines. Retrofit hardware is currently available in limited quantities, efficiency is equal to pure diesel operation, and risk of engine damage appears low (provided the aspirated ethanol is used to replace diesel fuel rather than to boost power). The primary disadvantages of the approach are its moderate conversion costs and the inconvenience of its separate fuel tanks.

The value of ethanol in this application will be estimated at its heat value, or:

Proof	Energy content (Btu)	Volumetric value relative to No. 2 diesel
200	76,152	.55
190	72,344	.52
160	60,921	.44
120	45,691	.33

2. Other Uses

Potentially, ethanol could serve as a substitute for other farmstead energy requirements, including grain drying and livestock confinement heating. For these purposes a lower proof ethanol would be satisfactory.

In order to use ethanol in crop dryers, the major modification would be to the burners. The relative value of ethanol in grain drying compared to propane can be estimated based on the energy content of the two fuels. The energy that can be obtained from burning a gallon of propane is 81,855 Btu compared to 76,152 Btu for ethanol. If substitution were strictly on a Btu basis then 1.07 gallon of ethanol would be required to replace 1 gallon of propane.

If ethanol is to be substituted for fuel oil in the heating of buidings, then based on energy content (76,152 Btu for ethanol; 138,690 Btu for fuel oil) 1.8 gallons of ethanol would be required to replace one gallon of fuel oil. The

flash point of ethanol ($55^{O}F$) is considerably lower than that for fuel oil making it less attractive than fuel oil for heating homes and commercial buildings.

While ethanol could be used for these purposes, there are also other sources of energy on the farm (crop residues in particular) that would serve equally well for such stationary applications. A multi-purpose, big bale burner is commercially available for supplying heat from biomass, and this approach would conserve liquid fuels (ethanol, fuel oil, or LPG) for the more demanding mobile energy needs.

F. Summary

The feasibility of the seven engine applications discussed in this report is summarized in Table II-5. The "percent fuel replaced" column refers to the amount of petroleum fuel (either gasoline or diesel fuel) that ethanol might replace for those engines that are actually converted to ethanol.

Near-and long-term potentials are highly subjective, and the introduction of new additives or engine technologies could alter this assessment. Only carbureted diesel operation is given a high near-term potential, while the other three diesel applications are judged to have low near-term potential. All spark ignition applications are given moderate ratings.

Two applications are given high long-term (5 years hence) ratings. If properly implemented, both the standard CR spark engine and the multifuel diesel could be switched between ethanol and petroleum fuel very quickly, giving them added flexibility. Ethanol-diesel mixtures would probably require both cetane improvers and cosolvents, so this application was given a low long-term rating.

Table II-5. Summary of ethanol application in engines

Application	Engine population	Approx % fuel replaced[a]	Utilize low proof?	Near term potential	Retrofit costs	Long term potential	200 proof ethanol value	Potential problems
1) Ethanol-gasoline mixtures	Vehicles and older S.I. tractors	10	No	Moderate[c]	Very low[c]	Moderate	.75 x gasoline	1, 2, 5, 7
2) Ethanol in S.I. Std. CR	Vehicles, nat gas trr. engines, old S.I. tractors	100	Yes	Moderate	Low	High	.67 x gasoline	3, 4, 7, 9
3) Ethanol in S.I. High C.R.	Nat gas Irr engines old S.I. tractors	100	Yes	Moderate	Moderate	Moderate	.76 x gasoline	3, 4, 7, 9
4) Ethanol in S.I. converted diesels high C.R.	C.I. tractors, combines	100	Yes	Low	High	--	.52 x diesel	4, 6, 7, 9
5) Ethanol in diesels	C.I. tractors, combines	100	Yes[b]	Low[c]	High[c]	High	.55 x diesel	4, 5, 6, 7, 8, 10
6) Ethanol-diesel mixtures	C.I. tractors, combines	10	No	Low[c]	Low	Low[c]	.51 x diesel	1, 4, 6, 7, 10
7) Carbureted ethanol C.I.	C.I. tractors, combines	30	Yes	High	Moderate	Moderate	.55 x diesel	11

a/ Assuming 100% adoption
b/ Speculative
c/ Would become more favorable with the development of low cost additives

Potential Problem Areas

1) Phase Separation
2) Driveability
3) Valve Recession
4) Starting (below 40°F)
5) Vapor Lock
6) Unavailability of Retrofit Conversion Hardware
7) Materials Compatability
8) Injector Pump Lubrication
9) Oil Dilution at Light Loads
10) Combustion Knock
11) Inconvenience

SUMMARY

III. LIQUID FUEL USE PROFILE

Although the potential uses of fuel ethanol include those to power agricultural and commercial mobile and stationary engines, grain dryers, and boilers, its practical near-term use will be as a fuel for mobile engines. Utilized as pure 200 or low proof ethanol or blended at 200 proof with either gasoline or diesel fuel, its most efficient use requires combustion units designed specifically to utilize ethanol.

Agricultural engine fuel usage varies greatly by geographic area and type of farm. Over 3 billion gallons of gasoline and 2.6 billion gallons of diesel fuel were used on farms in 1974. To replace these fuels with 190 or lower proof ethanol would require modifications or adaptations of engines and burners (see Chapter II). The rate at which such substitution could take place would depend upon the rate at which the necessary modifications to or replacement of present equipment occurs.

The current and near-term commercial market for 200 proof ethanol is greatest for blending with--extending--unleaded gasoline. A blend of 10 percent ethanol and 90 percent gasoline may be burned satisfactorily in unmodified gasoline engines. Substitution of the 38.6 billion gallons of unleaded gasoline used in 1978 with the 10-90 blend would require 3.86 billion gallons of ethanol. The use of lower proof ethanol as a gasoline extender will require the development of environmentally acceptable emulsifiers or blending agents.

The use of ethanol as an extender for diesel fuel is dependent upon the development of cetane improvers.

III. LIQUID FUEL USE PROFILE

Uses for ethanol as a liquid fuel include those for mobile and stationary engines, grain driers, and boilers. In the near term, its primary use will be as a fuel for mobile engines. Ethanol may be utilized either as a blend of 200 proof with gasoline, and perhaps diesel, straight at 200 or lower proofs, or aspirated with diesel fuel. The quantities and specific applications of each type of ethanol fuel depend to some extent on the rate at which necessary modifications or adaptations of present equipment and the rate of replacements of equipment currently in use occur. The present liquid fuel consumption on farms and in the transportation sector for which ethanol fuels may be a complete or partial substitution or an extender are discussed below.

A. On Farm Utilization

On-farm fuel usage by type of operation has been compiled by USDA for 1978. These data are subdivided to show energy usage associated with crop production operations from preplant through harvest to grain drying and those associated with livestock operations. For each of the separate operations, the quantity of fuel used is compiled. These data, shown in Table III-1, indicate that for the U.S., 83 percent of the gasoline used on farm (exclusive of household use) was used for crop operations and 17 percent for livestock operations. Crop operation accounted for 85 percent of diesel fuel use and livestock operation for 13 percent. Crop operations accounted for 78 percent of LP gas use and livestock operations for 22 percent. Usage in individual states varies from these national averages as shown below for Minnesota and Illinois.

	Gasoline	Diesel	LP
	---------Percent	of Total	---------
Minnesota			
Crop	87	86	60
Livestock	13	14	40
Illinois			
Crop	93	83	92
Livestock	7	17	8

Fuel usage per farm varies widely by geographic area. Preliminary 1978 data compiled by USDA show variations by region in the fuels and lubrication cost per acre for grains. The values for corn given below exemplify these variations.

Table III-1. United States, energy and agriculture, 1974 data base, summary by operation

	Gals of gasoline	Gals of diesel	Gals of fuel oil	Gals of LP gas	Cu ft of nat gas	Tons of coal	Kwh's of elect.
	(000)	(000)	(000)	(000)	(mil)	(mil)	(mil)
Operations-Crops							
Preplant	61,424	923,331	--	22,719	--	--	--
Plant	25,581	242,480	--	9,461	--	--	--
Cultivate	24,476	280,338	--	9,053	--	--	--
Fertilizer application	27,023	64,044	--	9,995	--	--	--
Pesticide application	32,711	74,754	--	12,099	--	--	--
Irrigation	70,553	177,144	--	236,331	132,318	--	19,264
Frost protection	46,443	39,326	218,549	1,458	--	--	200
Harvest	495,052	443,729	--	183,102	--	--	--
Farm truck	538,405	5,605	--	--	--	--	--
Grain handling	16,314	--	--	--	--	--	33
Crop drying	--	--	76,564	664,440	27,182	--	858
Farm pickup	1,036,304	1,058	--	--	--	--	--
Farm auto	442,722	--	--	--	--	--	--
Elect. overhead	--	--	--	--	--	--	1,705
Miscellaneous	64,283	35,354	--	--	--	--	--
Total-Crops	2,881,276		295,112	1,148,657	159,500	--	22,060
Operations-Livestock							
Lighting	--	--	--	--	--	--	1,653
Feed handling	149,633	195,283	--	--	--	--	1,073
Waste disposal	98,036	44,645	688	6,754	435	--	123
Water supply	--	25,511	--	--	--	--	1,605
Livestock-Handling	19,391	1,033	--	--	--	--	--
Space heating	--	1	--	55,957	10	--	174
Ventilation	--	--	--	--	--	--	2,014
Water heating	--	--	--	70,737	--	--	975
Milking	--	--	--	--	--	--	820
Milk cooling	--	--	--	--	--	--	1,344
Egg handling	--	--	--	--	--	--	31
Brooding	--	--	8,129	188,120	4,181	32,725	--
Farm vehicles	233,310	69,330	--	469	--	--	--
Farm auto	198,417	--	--	--	--	--	--
Other	118,578	16,613	--	10,848	--	--	215
Total-Livestock	817,365	352,416	8,817	332,885	4,625	32,725	10,028
Total-Agriculture	3,698,641	2,638,955	303,929	1,481,542	164,125	32,725	32,088

Source: U.S. Department of Agriculture/Federal Energy Administration, Energy and Agriculture, 1974 Data Base, 1977.

Region	Corn Production Fuels and Lubrication Cost Per Acre
	($)
Northeast	5.92
Lake States/Corn Belt	6.11
Northern Plains	16.06
Southeast	6.95
Southwest	28.30
United States	8.41

Corn production in the Southwest is predominately irrigated and therefore has high energy cost per acre.

Variations also occur by type of farm. Table III-2 shows the fuel, oil, and grease expenditures per tillable acre for several types of Illinois farms--both grain and livestock. The livestock farms use about 50 percent more petroleum products than do the grain farms. Fuel usage for farms in two areas of Minnesota are about the same as for grain farms in Illinois. Fuel usage on Kansas farms (Farm Management Summary and Analysis, 1978) is less than on either Illinois or Minnesota farms, a rate which probably reflects the lower tillage energy requirements for wheat and milo compared to those for corn and soybeans.

Fuel usage per acre is relatively independent of farm size as shown in Figure III-1 where fuel expenditures are shown for grain and hog farms in Illinois. There seems to be little economy of scale as far as fuel usage is concerned.

Table III-3 shows the consumption of gasoline, diesel, and LP fuels per cropped acre in the U.S. The large amount of LP in the corn belt area probably reflects its large energy requirements for drying of grain. Relatively large amounts of LP in drier regions probably reflect more the use of LP for irrigation pump engines. Alcohol could be used for crop dryers with little modification of burners. LP engines used for irrigation would also require minimum modification and would probably have higher compression ratios and utilize alcohol more efficiently.

The over three billion gallons of gasoline used annually on farms reflects its business use in trucks and automobiles as well as combines (which use a higher percentage of gasoline engines than do the larger tractors). The problems of converting these engines to alcohol were discussed in Chapter II.

More than 3.3 billion gallons of diesel fuel are used annually on farms. Conversion of diesel tractors to alcohol fuels can occur through retorfitting or replacement. This conversion will be more difficult than that for gasoline or LP, but the existing use of gasoline and LP indicate that much alcohol of either 190 or 200 proof can be absorbed by the agricultural sector without waiting for the conversion of diesel tractors.

Table III-2. Fuel, oil and grease expenditures per tillable acre

Type of operation	Fuel, oil and grease
	$/tillable A
N. Illinois, High production Soil, grain 1/	8.02
N. Illinois, Low production Soil, grain	8.11
S. Illinois, Grain	8.19
N. Illinois, High production Soil, Hog	13.52
N. Illinois, Low production Soil, Hog	13.58
S. Illinois Hog	11.90
N. Illinois Dairy	13.73
S. Illinois Dairy	14.17
N. Illinois Beef	11.70
S.E. Minnesota 2/	9.80
S.W. Minnesota 3/	8.78
Kansas 4/	6.78

1/ Summary of Illinois Farm Business Records, 1978, Univ. of Ill.

2/ Southeastern Minnesota Farm Management Association, 1978 Report, Univ. of Minn.

3/ Southwestern Minnesota Farm Management Association, 1978 Report, Univ. of Minn.

4/ Farm Management Summary and Analysis, 1978, Kansas State University.

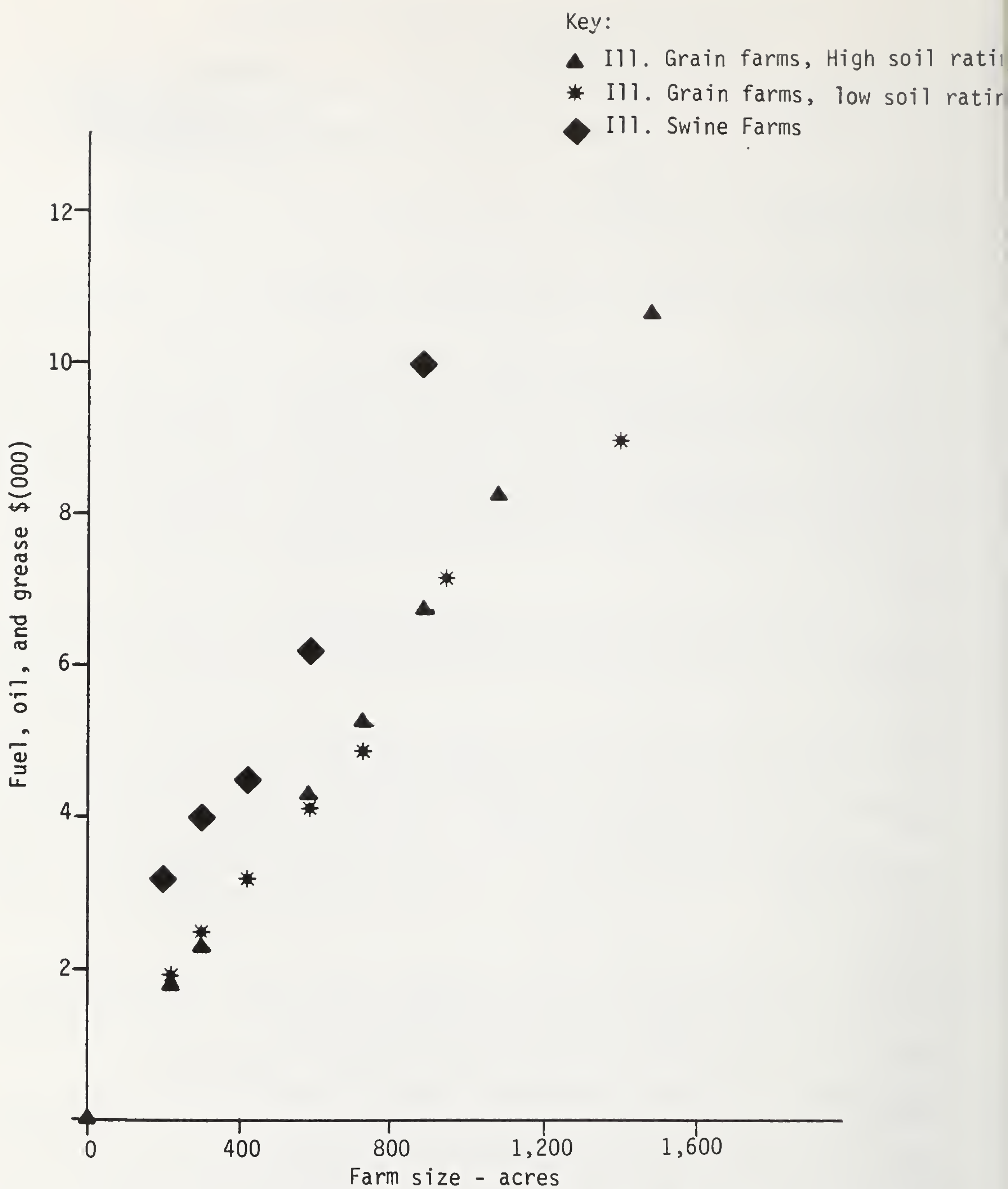


Figure III-1. Fuel, oil and grease expenditures for selected Illinois farms.

Source: Summary of Illinois Farm Business Records. University of Illinois, 1978.

Table III-3. Agricultural fuel use by state[1/]

State	Crop Area[2/]	Fuel Use[3/] Gasoline	Diesel	LP	Fuel Use Gasoline	Diesel	LP
	(mil A)	(mil gals)			(Gal/A)		
Alabama	3.66	38.6	37.6	24.0	10.5	10.3	6.56
Alaska	.023	.282	.048	.064	12.3	2.1	2.78
Arizona	1.52	24.1	16.5	1.30	15.9	10.9	.86
Arkansas	7.82	71.3	94.6	57.4	9.12	12.1	7.34
California	9.74	157.4	166.2	24.9	16.16	17.06	2.56
Colorado	9.67	50.1	45.8	8.53	5.18	4.74	.88
Connecticut	.178	4.05	1.65	2.00	22.75	9.27	11.24
Delaware	.515	10.3	5.70	7.08	20.0	11.1	13.8
Florida	3.11	78.8	88.5	22.0	25.3	28.5	7.0
Georgia	5.32	68.7	62.6	54.9	12.9	11.8	10.3
Hawaii	.320	9.00	6.49	.173	28.1	20.3	.5
Idaho	5.52	42.1	41.3	6.77	7.6	7.5	1.2
Illinois	23.1	268.0	130.0	139.0	11.6	5.6	6.0
Indiana	12.7	144.0	67.0	73.9	11.3	5.3	5.8
Iowa	24.5	328.0	165.0	143.0	13.4	6.7	5.8
Kansas	27.7	149.0	136.0	45.0	5.4	4.9	1.6
Kentucky	4.91	59.4	34.4	15.9	12.1	7.0	3.2
Louisiana	4.64	48.0	68.6	10.5	10.3	14.8	2.3
Maine	.555	7.98	3.06	.844	14.4	5.5	1.5
Maryland	1.63	25.4	11.5	13.5	15.6	7.1	8.3
Massachusetts	.209	4.22	1.89	.985	20.2	9.0	4.7
Michigan	7.43	85.4	48.6	21.8	11.5	6.5	2.9
Minnesota	21.9	244.0	109.0	89.9	11.1	5.0	4.1
Mississippi	6.23	56.7	70.9	19.8	9.1	11.4	3.2
Missouri	13.8	140.0	75.8	46.1	10.1	5.5	3.3
Montana	14.8	58.5	29.4	5.86	4.0	2.0	.4
Nebraska	20.1	141.0	241.0	149.0	7.0	12.0	7.4
Nevada	.600	8.30	8.53	1.99	13.8	14.2	3.3
N. Hampshire	.131	1.85	.591	.436	14.1	4.3	3.3
N. Jersey	.631	15.1	6.89	1.76	23.9	10.9	2.8
N. Mexico	1.76	26.8	19.3	18.1	15.2	11.0	10.3
New York	4.86	74.9	29.0	11.6	15.4	6.0	2.4
N. Carolina	5.48	66.1	56.7	143.0	12.1	10.3	26.0
N. Dakota	28.0	124.0	98.4	5.79	4.4	3.5	.2
Ohio	11.2	119.0	51.6	38.7	10.6	4.6	3.5
Oklahoma	11.2	103.9	62.0	21.5	9.3	5.5	1.9
Oregon	4.46	30.7	23.7	6.50	6.9	5.3	1.5
Pennsylvania	5.00	74.0	32.9	18.7	14.8	6.6	3.7
Rhode Island	.024	.507	.169	.097	21.1	7.0	4.0
S. Carolina	2.86	29.8	30.2	26.2	10.4	10.6	9.2
S. Dakota	16.9	89.0	104.4	31.3	5.3	6.2	1.8
Tennessee	4.87	50.4	37.8	10.7	10.3	7.8	2.2
Texas	24.6	264.0	182.0	67.3	10.7	7.4	2.7
Utah	1.54	14.8	11.8	3.01	9.6	7.7	1.9
Vermont	.570	8.55	1.54	2.32	15.0	2.7	4.1
Virginia	3.00	33.3	27.4	29.6	11.1	9.1	9.9
Washington	7.68	43.0	31.7	7.30	5.6	4.1	.9
W. Virginia	.878	9.13	4.28	2.82	10.4	4.9	3.2
Wisconsin	10.1	178.0	45.1	46.6	17.6	4.5	4.6
Wyoming	2.79	17.6	14.2	1.76	6.3	5.1	.6
Total		3,697.1	2,639	1,481.3			

1/ Excludes fuel oil which is mainly used for frost protection.

2/ U.S. Department of Agriculture, Agricultural Statistics, 1978.

3/ U.S. Department of Agriculture/Federal Energy Administration, Energy and Agriculture, 1974 Data Base, 1977.

States with intensive agricultural production, including livestock and truck crops, use significantly larger amounts of fuel per crop acre. These data should be useful in estimating fuel usage in small areas of a particular state.

In addition, these data may be used to calculate the quantities of 200 proof ethanol required to replace the fuels used on an average farm. Using data for fuel usage per acre (Table III-3) and an average size farm in the state, the fuel requirements for the farm are estimated. By combining this information with the relative volumetric values for specific engines or other uses (Chapter II), the quantity of alcohol required for replacement may be obtained. The calculations for an average Illinois farm of 272 acres requiring a total of 10,410 gallon of 200 proof ethanol (to replace the gasoline, diesel fuel and LPG) are shown below.

Fuel	Gal/acre	Total Fuel (gal)	Volumetric Value Relative to 200 Proof Ethanol	Ethanol for Total Replacement (gal)
Gasoline	11.6	3,160	1.5	4,740
Diesel	5.6	1,520	1.8	2,740
LPG	6.0	1,630	1.8	2,930

Similarily, an individual could, by using data for his own farming operation, determine the ethanol required for liquid fuel replacements for his own farming operation and thus sizing requirements for an ethanol production facility.

B. Commercial Market for 200 Proof Ethanol

The current-and-near-term potential market for 200 proof ethanol is probably greatest as a blending agent in the production of gasohol--10 percent alcohol and 90 percent unleaded gasoline.

The 1978 consumption of unleaded gasoline in the U.S. is estimated to be about 38.6 billion gallons (Monthly Energy Review, September, 1979). At the 1978 rate of consumption, if one percent of this volume were replaced with ethanol for gasohol, 386 million gallons of 200 proof ethanol would be required. If the entire unleaded market were replaced with gasohol, a total of 3.86 billion gallons of ethanol would be required.

The future use of lower proof ethanol as an extender in gasoline is dependent on the development of suitable environmentally acceptable emulsifying or blending agents.

The potential for ethanol as an extender for the 48.2 billion gallons of distillate fuel oil produced in 1978 is less well established.

SUMMARY

IV. ETHANOL PRODUCTION

The principles of ethanol production and the physical and chemical properties of ethanol must be understood for they have implications for specific plant design criteria and for operating procedures. These factors are discussed in detail in this chapter. Actual plant design and operational requirements are discussed in detail in Chapter VII.

Principles of Ethanol Production

Ethanol production consists of three major steps:

- the formation of a solution of fermentable sugar,
- the fermentation of the sugars to ethanol, and
- the separation of the ethanol from the mixture, usually by distillation.

Production variations occur in the initial step and depend upon whether the raw material contains starch or sugar. Starch-containing materials--small grains and potatoes--require a hydrolysis (saccharification) step to convert the starch to fermentable sugar by using enzymes. Sugar-containing materials require a sugar extraction procedure but no hydrolysis.

As grain is currently considered one of the primary feedstock, the basic production steps outlined below assume the use of grain.

- Milling — The starch source such as corn, wheat, rye or barley is ground into a fine meal to expose their starch granules and to permit their suspension and dispersion in the following step.

- Slurrying — Water is added to the meal to form a mash (typically 10-33 gallons of water per 56 lb. bushel of grain). The pH is adjusted, and liquefaction enzymes are added.

- Liquefaction — The mash is heated to gelatinize the starch (150-200^{o}F) and render it susceptible to enzyme breakdown. The starch is converted into soluble high molecular weight sugars called dextrins by the enzyme alpha-amylase.

- Conversion — The mash is cooled to the conversion temperature of 135-140^{o}F. The pH is adjusted to about 4.2, and the conversion enzyme, glucoamylase, added. The mash is held long enough to permit some of the dextrins to be converted to fermentable sugars. It is then cooled further to the fermentation temperature of 85-90^{o}F. Solids, at this point, should be 8-12 percent, i.e. about 33 gallons per bushel of corn. Water can be added to aid cooling if high solids content was used in the previous steps.

- Fermentation — Distillers yeast is added and the mash is held until fermentation is complete, i.e. 48-120 hours. During this time the conversion enzyme continues to break down dextrins to fermentable sugar while the yeast converts these sugars to alcohol and carbon dioxide. As the fermentation process produces heat, cooling is necessary to maintain yeast survival.

- Distillation — The fermented mash is heated to vaporize the alcohol. The resulting vapors are collected and cooled to condense the alcohol back to a liquid. The residue contains the residual grain, spent yeast, and water. The residual grain and spent yeast are generally used in animal feeds.

Sugar-containing feedstock processing differs in that the first four steps are replaced with a sugar extraction procedure. In addition, the residual composition varies from that obtained from grain and may be of much lower value.

Throughout the process, reaction conditions such as temperature and pH must be maintained to within narrow limits if an optimum production of ethanol and high quality residues are to be obtained. The systems' required physical design and controls are discussed in Chapter VII.

Other Considerations

Ethanol is volatile, flammable, and potentially explosive in certain mixtures with air; therefore, great care must be exercised when producing and storing ethanol. The potential for explosions and fire from alcohol vapors must be recognized and preventative measures incorporated into both the plant design and operational procedures for producing and storing alcohol. For example, there should be no open flames and all motors and switches should be explosion proof. These and other features are discussed in detail in Chapter VII.

Regulations unique to ethanol production are imposed by the Bureau of Alcohol, Tobacco and Firearms (ATF). Prior to any distillation an ATF permit must be obtained. Two types are available--experimental or commercial. Complete details are available from regional ATF offices.

Each ethanol production facility must also abide by the appropriate state and national environmental regulations. Unless proper technologies are incorporated into the plant design, adverse environmental impacts may result from boiler operations (air emissions, fly and bottom ash), cooling and process water dischargers, wet stillage handling, and the disposing of "bad" batches. These impacts may be virtually eliminated with proper plant design and operating techniques.

IV. ETHANOL PRODUCTION

The principles underlying the production of ethanol by fermentation have been long known, and if maximum ethanol yield is to be obtained, these principles must be taken into consideration in the design and operation of an ethanol production facility.

Ethanol may be produced from sugar and starch base feedstocks. In order that the yield of ethanol be maximized, it is imperative that process reaction conditions such as pH and temperature be maintained within narrow limits. Standards of cleanliness must be maintained to prevent competing reactions and, thus, a reduction in alcohol yields, and to prevent, also, the contamination of the stillage. These factors have implications for plant design and operating conditions.

Other considerations are necessitated by the physical and chemical properties of ethanol. Its volatility and flammability have safety implications for both the production process and storage. Governmental regulations imposed because of ethanol's potential consumption as a beverage necessitate suitable equipment for handling and denaturating.

The principles involved in ethanol production and the physical and chemical properties of ethanol having implications for plant design, operating procedures, and operator skill are discussed below. The actual plant design criteria and operating procedures are discussed in Chapter VII.

A. Principles of Ethanol Production

Regardless of the feedstocks used, ethanol production consists of three major stages: the formation of a solution of fermentable sugars, the fermentation of sugars to ethanol, and the distillation of the ethanol (Universal Foods, 1979). The variations in production because of different raw materials occur in the initial part of the first step, that is, the processing of the raw material to ultimately obtain the fermentable sugars. Grains or other starch-containing materials first require a reaction of the starch with water (hydrolysis) in the presence of enzymes to produce a simple sugar solution. The second step--fermentation, the using of yeast to convert the sugar to ethanol and carbon dioxide--is the same for all feedstocks. The fuel alcohol is then obtained by distillation of the ethanol-water mixture. These basic process steps are shown schematically in Figure IV-1 and discussed in greater detail below.

The production variations occur in the initial step depending on whether the raw materials contain starch or sugars. For cereal grain, there are essentially four possible variations in the process. Three processes utilize the whole grain with the variations resulting from the point at which spent grains are removed. As shown in Figure IV-1, the spent grains may be removed prior to fermentation, after fermentation, or during initial distillation. The fourth process is a dry or wet milling process in which oil, germ, hulls, etc. are separated initially from the starch. In each, only the starch portion is then hydrolyzed for subsequent fermentation.

Potatoes require careful washing (to remove soil microbes) and cooking prior to the hydrolysis step. Sugar-containing materials such as sugar beets, sugar cane, and sweet sorghum require a sugar extraction procedure but no hydrolysis.

As emphasis currently is centered on ethanol production from grain, the production process described will be primarily that of using small grains as the raw materials.

1. Formation of Fermentable Sugars

The first part of the production of ethanol via fermentation consists of preparing a solution of fermentable sugars in a concentration range of 15 to 25 percent sugars. Basically, this involves four steps--milling, slurrying, liquefaction, and conversion. These steps will be described for the most part in terms of using corn or other grains as the raw materials. Some variations required for other feedstocks will also be noted.

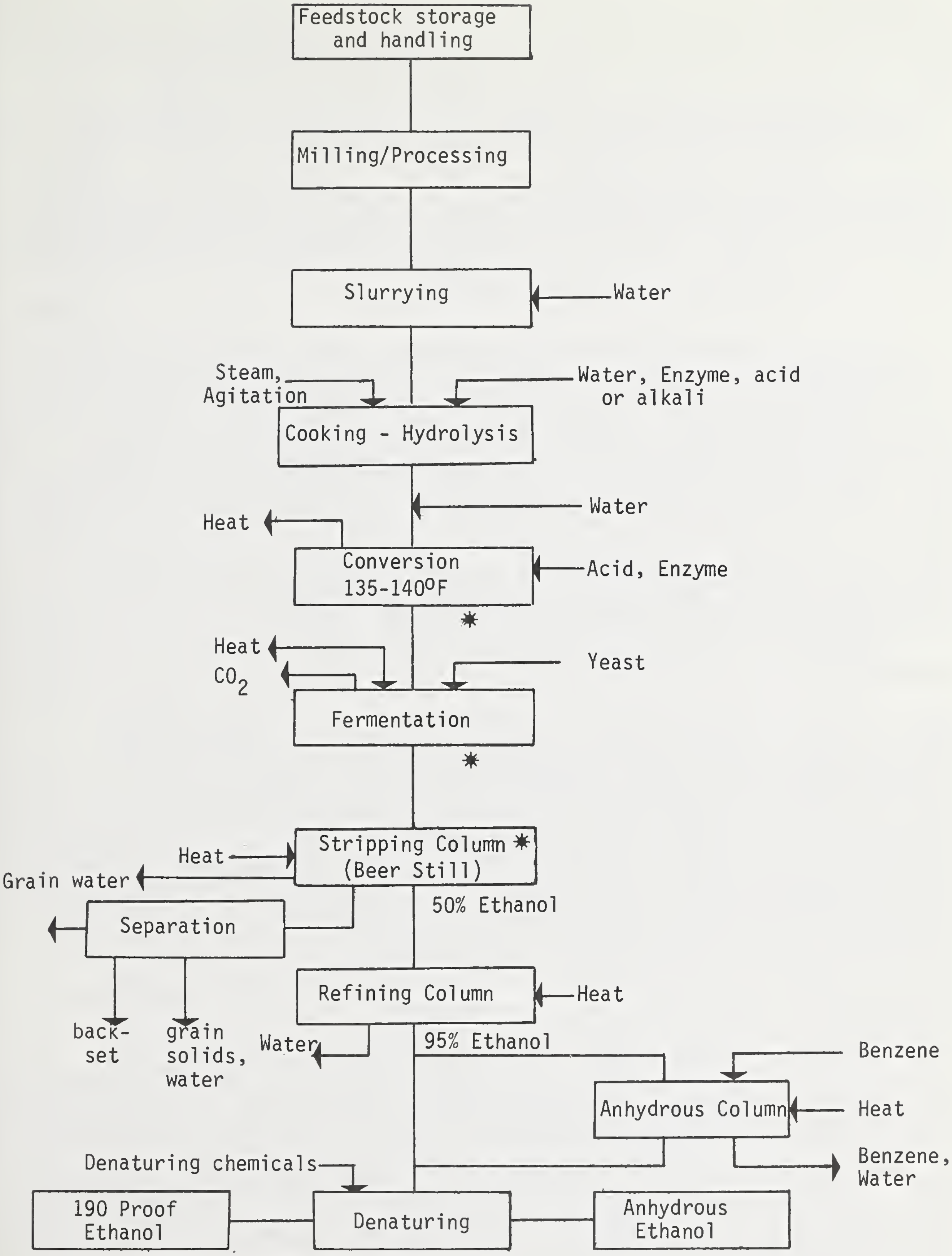
a. Milling

The first step involves mechanical processing of the starch source to a fine meal in order to expose the starch granules. This permits suspension and dispersion in the following step.

b. Slurrying

Slurrying involves adding the meal to water to form a mash. Typically 10-33 gallons of water are used for each 56-pound bushel of grain. The pH is adjusted to the value specified by the enzyme supplier--typically 5.2-6.0. Lime may be used for this pH adjustment if enzymes requiring higher levels of calcium are used.

In some distilleries, "set back" is used for a portion of the required liquid. The stillage removed from the stripping column is separated by a centrifuge or a sieve to give low-and high-solids fractions. The low-solid fraction may be utilized to provide a part of the process liquid. This fraction, when so used, is called "back set" or "set back" and provides a buffering action that helps to maintain a more nearly constant pH of the solution and is a water and an energy conservation measure for continuously operating plants. The percent of back set that should be used for maximum efficiency has not yet been determined. (In the beverage industry, the back set defined by law as 25 percent is added to the fermenter in the production of sour mash bourbon.)



*/ Spent grain may be removed here.

Figure IV-1. Schematic ethanol production diagram.

Source: Shelton, D. and A.R. Rider, "Ethanol Production Equipment and Processes," Ethanol Production and Utilization for Fuel, Cooperative Extension Service, Institute of Agriculture and Natural Resources, Univ. of NB, Lincoln, October 1979.

c. Hydrolysis

Hydrolysis may be divided into two distinct steps--liquefaction and conversion. The starches of small grains are susceptible to gelatinization at low temperatures; for instance, wheat and granular wheat flour may be gelatinized sufficiently at 155^{O}F in 30 minutes and rye at 145^{O}F in 30 minutes or less. Cornstarch is evidently gelatinized in two steps: approximately 80 to 85 percent at 160^{o} to 165^{O}F; the remainder is gelatinized only as the temperature is increased, with the final 2 to 5 percent requiring treatment at temperatures above 212^{O}F and up to 350^{O}F, depending on the reaction time. Since corn is the most widely used raw material, almost all distillers employ either batch-pressure or continuous-pressure cooking systems to attain the maximum yield of alcohol (Underkoffer, 1954).

Traditionally, in the beverage alcohol industry, enzymes found in sprouted malt have been utilized for hydrolysis, but today there are commercially available enzymes to effect the hydrolysis that are capable of working effectively under a wider range of conditions, of temperature, and of pH than can the malt enzymes. The specific enzyme determines the optimum temperature and pH. Commercially these enzymes are produced for fermentation from bacteria, molds, or other organisms. Alpha-amylase, used for the liquefaction, i.e. to liquify starches, may be obtained from Bacillus subtilis, Aspergillus oryzae and Bacillus licheniformis. The glucoamylase used for the conversion step completes the hydrolysis by converting the dextrins to simple sugars and may be derived from selected strains of organisms such as Aspergillus niger and Rhizopus niveus.

Liquefaction

During liquefaction the starch is converted into soluble high molecular weight sugars called dextrins. The mash is heated to (150-200^{O}) with alpha-amylase to gelatinize the starch and render it susceptible to further enzymatic breakdown. As the temperature in the heating cycle reaches 150^{O}F, the starch gelatinizes (hydrates) and the mash rapidly thickens. As the temperature is increased to 160^{O}, adequate agitation to prevent the viscosity from becoming excessive is imperative. Provided the temperature increase is slow and there is proper agitation, the alpha-amylase will hydrolyze (liquify) the starch as it becomes gelatinized and no problems will be encountered. Should heating of the mash be too rapid and the viscosity increase too much for efficient agitation, the heating and agitation should be stopped until the viscosity is reduced by the enzyme action. The heating should be continued to at least 170^{O}F and preferably to boiling to obtain a more efficient reaction. Depending on the commercial alpha-amylase used, the enzyme may be added to the slurry prior to cooking or during cooking or both. Pressure cooking may also be used, although more elaborate equipment is required. The temperatures and steam pressures used range from 250^{O} at 15 pound pressure for 15 minutes to 360^{O}F at 160 pounds pressure for 30 seconds (Crombie, 1979). Pressure cooking has the advantages of more greatly insolubilizing the protein to allow easier removal, of somewhat decreasing the foaming of the protein in the mash during fermentation, and of offering a greater degree of sterilization.

Many designs and techniques are used for both batch processing and continuous flow cooking, but the essential feature of all is to efficiently liquify the starch contained in the feedstocks.

At this point in the process, the original starch has been converted to dextrins--high molecular weight sugars. These sugars are not fermentable by yeasts.

As the pH drops during the hydrolysis, pH adjustment may be needed prior to the addition of the glucoamylase, for the optimum conditions for its action are a temperature of 140°F and a pH of 4.2.

Conversion

The final step in this segment of the process is conversion of the dextrin to fermentable sugars. For this step the mash is cooled to the conversion temperature of 135-140°F, and the pH is adjusted for the specific enzyme used. Conversion enzymes--glucoamylase---are added. The mash is held at this temperature only long enough to permit a portion of the dextrins to be converted into fermentable sugars. The mixture so obtained, called the "sweet wort," is then cooled further to the fermentation temperature of 85-90°F.

It is not necessary that complete conversions of the dextrins occur prior to the addition of the yeast. As soon as sufficient sugars are available to support a yeast population, the fermentation process may be initiated. At this point the mixture should be about 8-12 percent solids (33 gallons liquid per bushel); hence, water may be added to aid cooling if the solids content is high.

Potato processing varies because the material requires careful cleaning prior to cooking. If sugar containing feedstocks such as sugar cane, sugar beet, or sweet sorghum are used, then in principle the above process is simplified. All that is required is that the sugars be extracted from the crushed or shredded raw materials by using hot water or steam depending upon the feedstock used. These are the same extraction procedures that are utilized in the sugar and cane syrup production process. No hydrolysis step is required. The sugar concentration is adjusted prior to the fermentation step.

2. Fermentation

In the fermentation step, yeasts convert sugar into ethanol and carbon dioxide by an anaerobic process. Theoretically from 100 pounds of sugar, 7.7 gallons (51.1 pounds) of ethanol and 48.9 pounds of carbon dioxide are produced. Small quantities of fusel oil, succinic acid, and glycerol are also obtained. Provision must be made to vent the carbon dioxide produced and prevent oxygen from entering the reaction vessel. Yeast, specially designed for distillers use in fermentation, is commercially available. For example, if a dry yeast is used, it is first rehydrated with 3 to 5 times its weight of warm (110°F) water for a period of 5 to 10 minutes. The recommended 2 to 4 pounds of dry yeast per 1,000 gallons of mash

will result in an inoculum of 5-10 million yeast cells per milliliter. The optimum fermentation conditions are a temperature of 30°C (86°F) and a pH of 4 to 5. When the grains are left in the sweet wort or when back set is utilized, a buffering capacity is added that assists in maintaining the required pH (acidity). The expected alcohol yield from a 15-25 percent solution of fermentable sugars is 6.75 to 11.25 percent by weight.

The time required for the completion of the fermentation is dependent upon the strain of yeast used. A variety of yeasts were tested for molasses fermentation in order to find a yeast strain that is highly efficient under variable conditions. (A group of 12 so tested are listed in Table IV-1.) The ATCC 4132 produced 93 to 95 percent of the theoretical yield of alcohol from molasses without molasses pretreatment. The remainder of the yeasts were less efficient in alcohol production with the 48-hour fermentation efficiency ranging down to 35 percent. (Heinz, September 11, 1979)

For small-scale production, the most readily available yeast is active dry yeast especially designed for distillers use in grain mash fermentation. These products have been found to work well for beet, cane, and citrus molasses fermentation. This yeast is designed to produce uniform, rapid fermentation and maximum alcohol yields under a wide range of temperatures and pH. The time required for fermentation will vary with the temperature, although most estimates are for 48 to 72 hours.

Yields of alcohol may be reduced if there is any contamination of the sweet wort. Contamination with undesirable micro-organisms will decrease the yield of alcohol as these will compete with the yeast for the sugar. Prior to the additions of the yeast, contamination may occur readily in the cooling of the sugar mixture from external sources or from the equipment itself.

At this point in the process, the sugar solution is a suitable medium for growing a variety of microbes that may be pathogenic or produce toxic substances (Crombie, 1979). Microbes could be introduced with the raw materials initially, via the addition of cooling water, or from the air; thus, provision in the design needs to be made for high quality water and some protection from possible contamination from the air. Fortunately the contamination problem is mitigated by the fact that yeast populations grow quite rapidly, and overwhelm many of the potential competing organisms. In addition, the initial inoculation introduces a large yeast population that allows the yeast a head start. Provided care is exercised and, thus, unwanted microbial action does not occur, decreases in the yield of ethanol resulting from competing reactions can be held to a minimum.

Undesirable microbial reactions occurring in the fermentation step may produce unwanted substances in the stillage, but since these cannot be predicted in advance and would be batch specific, they would need to be handled on an individual batch basis. The contamination problem has implications for the design of the production facility and for the training of the process operator. The plant must be designed then in such a fashion that sanitation is readily accomplished and contamination of the sweet wort may be avoided when reasonable care is exercised. Once the operating procedures for a plant are finalized, these problems should be minimal.

Table IV-1. Yeast strains and their relative fermentation efficiency

Yeast strain	Yeast strain 48-hr fermentation efficiency	Ethanol per ton molasses
	(%)	(gal)
ATCC 4132	93	73
CBS 1237	90	70
Y 7494	86	67
UCD 505	83	65
UCD 595	81	63
ATCC 26603	81	63
DADY	77	60
BAKER	77	60
ATCC 26602	62	48
NCYC 90	57	44
Y 2034	55	43
CBS 1235	35	27

Source of yeast

ATCC	American Type Culture Collection
CBS	Centraalbureau voor Schimmelcultures, The Netherlands
Y	Northern Region Research Center, USA
UCD	University of California, Davis
DADY	Universal Foods Corporation
BAKER	Local procurement
NCYC	National Collection of Yeast Culture, Brewing Research Foundation, England.

Source: Heinz, Don J., Technology of Ethanol Production, Experiment Station, Hawaiian Sugar Planters' Association, Media Briefing on Energy, September 11, 1979.

All equipment currently being marketed utilizes a batch fermentation process; however, continuous fermentation units have been used in some industrial applications. A continuous fermentation process allows the use of smaller fermentors and supplementary equipment; it has been of interest for many years.

Continuous fermentation methods have been used successfully on waste sulfite liquor in Europe. Since sulfite liquors are sterile and even antiseptic, continuous fermentation is possible and desirable. With fermentable substances such as molasses, any contamination is cumulative and soon spreads throughout the system to reduce yields. To some extent the contamination can be controlled by using penicillin or other antibiotics, but their use to control organisms competing for sugars and decreasing alcohol yields, creates another problem--the use of by-product feed. The antibiotic content of feeds for livestock is very carefully controlled by the Food and Drug Administration. FDA requires tests to show that antibiotics and their degradation products in the resulting by-product feeds are below the maximum allowable levels. Most of the antibiotics are destroyed in the drying process. One commercial ethanol producer looked at and experimented with a continuous process, but finally gave up due to contamination problems.

Continuous fermentation could conceivably work well if the fermentable solution could be sterilized. With grains or cellulose feedstocks, the grain particles and fiber present in the sweet wort make sterilizaton most difficult.

Although continuous fermentation offers a more rapid method for producing ethanol with smaller tanks, etc. problems remain to be worked out before the system is feasible for the small-scale operator using grains as a feedstock. Work is underway at the present time to develop continuous automated equipment for small-scale ethanol production.

If wheat is used as the feedstock, special provisions must be made for the additional foaming that occurs during fermentation due to the presence of the gluten protein. Three possibilities exist to handle this problem: increasing the capacity of the equipment over that for the same quantities of corn; using a defoaming agent; or removing the gluten protein prior to fermentation.

The fermentation process produces heat. As the optimum fermentation temperature is about 90°F, cooling is necessary in order for the yeast to survive and work efficiently. The formation of ethanol is accompanied by approximately 287 kcal/kg ethanol produced (517 Btu/lb or 3,418 Btu per gallon) (Alfa-Laval, undated). If insufficient cooling is provided, the fermentation times are increased. Where no provision is made for removal of the heat of fermentation, heat losses can occur in two ways: heat losses may result from the evolution of carbon dioxide and from convection and radiation from the walls and other surfaces of the fermentor vessel. Heat removal in the off-gas is relatively small, even though the gas is saturated with water vapor and its attendant evaporative cooling effect. If heat evolution is greater than that which can be dissipated by radiation, the increasing temperature of the contents results in a decreased yeast activity

and a greater heat release. The eventual heat balance results in slow fermentation in medium-sized fermentors. In large fermentors, the results can be incomplete fermentation with low alcohol yield and a high proportion of unconverted sugars. A variety of mechanical devices are available that provide either internal or external cooling.

The completion of fermentation is marked by the cessation of carbon dioxide production. At this point the alcohol-water mixture known as "beer" is ready for distillation.

3. Distillation

The final step is the distillation of the beer and the ultimate disposal of the stillage. The distillation process is subject to federal, state and, sometimes, local regulations. These will be discussed in detail below under "Other Considerations."

In the distillation step the fermented mash is heated to vaporize the alcohol and the vapors are collected, cooled, and condensed to produce alcohol. The residue contains the residual grain or other noncarbohydrate portion of the raw material, spent yeast and water.

More precisely, distillation is the process of separating the more volatile components of a mixture from the non-volatile or less-volatile components. This is accompanied by heating the entire mixture to vaporize the more volatile components first. These vapors, collected and cooled, are considered to be a liquid with a substantially higher concentration of the more volatile components. (Rider, 1979)

Fractional distillation is used to separate liquids having different boiling points or vapor pressures. This can be done since a mixture of two components having different boiling points will boil at a temperature between the boiling points of the individual liquids. Too, the vapor given off by boiling the mixture will contain a higher percentage of the more volatile component, i.e. the one with a lower boiling point.

Fractional distillation is used to separate the alcohol from an ethanol-water mixture. Ethanol, which boils at about 173^{o}F (78.3^{o}C), is more volatile than water which boils at 212^{o}F (100^{o}C). Depending on the relative volumes of ethanol and water in the original mixture, the boiling point will be between these two temperatures. However, at an ethanol content of 95.6 percent, an azeotrope or constant boiling mixture forms that has a boiling point slightly lower than the boiling point of pure ethanol. When this mixture is boiled, the vapors also contain 95.6 percent ethanol and 4.4 percent water. For this reason, ethanol cannot be concentrated to more than 95.6 percent (191 proof) by fractional distillation.

In practice, two fractional distillation columns are generally used to distill the beer containing 8 to 12 percent ethanol into 95 percent ethanol. The first, or stripping column, is used to produce a distillate containing about 50 percent ethanol and 50 percent water. This distillate is then passed to

the second or refining column for further distillation up to a 95.6 percent ethanol level.

In most instances, this will be the last distillation performed in small-scale plants. The alcohol would then be denatured and used in the 190 proof form.

If anhydrous (200 proof) ethanol is desired, additional distillation must be done. Benzene, ethyl ether, or other substances are added to the 190 proof alcohol, and this three-component mixture is then distilled. A three-component azeotrope or constant boiling mixture containing 7.5 percent water, 18.5 percent ethanol, and 74 percent benzene is formed. All the water, the benzene, and some of the ethanol, are removed to leave pure ethanol in the bottom of the column. This ethanol must be denatured according to Bureau of Alcohol Tobacco and Firearm formulas described below.

B. Other Considerations

In addition to the actual technical principles of ethanol production, several other factors need to be considered. These factors are important, for they impact on the successful operation of all ethanol production facilities and have implications for the design and location of the plant and for operator training. The extent to which these factors affect the operation may be dependent to some extent on the size and type of the facility. Each of these considerations--product storage and handling, safety, and regulatory and environmental requirements--all have implications for both plant design and operator training. (see Chapter VII).

1. Storage

After the ethanol is produced, proper handling and storage is essential. The physical characteristics of ethanol dictate the facilities required to store ethanol safely and maintain the proof attained through distillation. Ethanol is volatile, flammable, and has a flash point of 55^{o}F. It is also hydroscopic; i.e. it absorbs water rapidly from air.

Ethanol is defined by the National Fire Protection Association (NFPA), an organization which publishes standards optimally intended to reduce flammable liquid hazards, as a Class 1B flammable liquid, that is, it has a flash point below 73^{o}F (flash point of ethanol is 55^{o}F) and a boiling point above 100^{o}F. Though compliance with these standards does not eliminate all flammable and combustible hazards it does reduce them considerably.

Recommendations for handling and storing Class 1B liquids in commercial establishments are given in the Flammable and Combustible Liquids Code, 1977. Standards for tank storage, bulk plants, distillery ventilation, structures locations are outlined. Storage requirements for flammable and combustible liquids on farms and isolated construction projects are covered in the "Standard for the Storage of Flammable and Combustible Liquids on Farms and Isolated Construction Projects, NFPA 395."

In order to maintain the ethanol at the proof at which it was distilled, it is imperative that the liquid be stored in such a manner that it is not exposed to moisture, including humidity. Such storage requires capping that prevents water vapor entry and allows the venting of ethanol's volatile vapors. These types of vented caps are available commercially and must be used. If the ethanol is allowed to absorb water, then the energy used to obtain original higher proof material is wasted and the potential use of the ethanol is affected.

2. Safety Considerations

Alcohol is volatile, flammable, and potentially explosive in certain mixtures with air. Thus, great care must be exercised when distilling and storing ethanol. As any spark could ignite alcohol vapors, explosion-proof wiring, switches, and motors are mandatory in the area of the still. Open flames cannot be allowed in the area, and adequate ventilation, exit routes, and fire extinguisher locations must be planned. The potential for explosions and fire from alcohol vapor must be recognized and preventative measures incorporated in both plant design and operation procedures.

For example, the design of the still, especially the pot still must be such that the likelihood of stoppage within the system is eliminated or, at least, greatly minimized. Too, plant design must eliminate obvious spark sources and other obvious hazards, and a well-trained knowledgeable operator is imperative to avert problems should any unusual situation arise.

Another potential source of an explosion or fire hazard is the boiler used for steam generation. Again if the boilers are properly maintained according to the manufacturer's instructions, there should be little cause for concern; however, the use of biomass for boiler fuel may increase the likelihood of problems. Regulation of the biomass boilers may be somewhat more complicated than those using more easily metered liquid fuels. Proper maintenance and careful operating procedures can essentially eliminate the hazards associated with (commercially available) boilers.

There are a number of codes that should be adhered to in the building of the distilling plant: most notably, the flammable liquids code, the lighting protection code, the electrical code, and the life safety code should be considered. The codes are those of the National Fire Protection Association, the various states, or a combination of both. In many instances, the state adopts the NFPA Codes. Specific area code information is available through the state Fire Marshall's offices or from reputable design engineers.

3. Regulatory Factors

In addition to the safety and environmental regulations considered above, there are regulations unique to ethanol production imposed by the Bureau of Alcohol, Tobacco and Firearms (ATF). Prior to any distillation of ethanol, an ATF permit is required. At present there are two types of permits--experimental and commercial. Ethanol production plants for experimental or research purposes must be approved by ATF but no formal permit is required. For these plants ATF can waive some of the strict

regulations which apply to producers of alcoholic beverages and industrial alcohol. Because the alcohol--ethanol--utilized for fuel is the same as that used for beverage alcohol which is regulated by law, ATF must approve and inspect such plants to ensure that ethanol is not illegally diverted to beverage use to avoid excise tax payments. By law, ATF must closely regulate the distillation and the denaturating of the alcohol, whether it is to be mixed eventually with gasoline or burned directly as an alcohol fuel. Presently, ATF is reviewing the regulations with the view of expediting and simplifying the permitting process for fuel alcohol plants.

Commercial permits are required if the alcohol is to be sold. If the ethanol is to be used for nonbeverage purposes an operating permit is required. Every person intending to operate a distilled spirits plant must also file a distilled spirits bond to ensure the protection of the tax liabilities which attach to all spirits produced. The amount of the bond varies and depends upon the type and volume of operations conducted at the distilled spirits plant. In the case of a plant which conducts both production and storage operations, the sum of the bond must be sufficient to cover the taxes on the quantity of distilled spirits produced in any 15-day period as well as the taxes on the quantity of spirits held in the plant warehouses. The bond must be at least $10,000 but need not be more than $200,000.

A government lien is attached to the distillery and to the equipment used for the production of spirits. If a distiller is not the actual owner of the property, ATF Form 1602, Consent, must be filed to acknowledge that the property is used for distilling spirits. The consent also stipulates that the lien of the government is paramount to all other encumbrances, and recognizes that title to the property reverts to the government in the case of forfeiture. The government lien does not attach to the property if an indemnity is filed on ATF Form 3A, Indemnity Bond, to stand in lieu of future liens.

In addition to the bonding and permit requirements for registration, the applicant must also submit additional supporting information so that ATF may determine whether the application for registration should be approved. This supporting information includes but is not limited to the following:

1. listing of the distillery's major equipment, a description of its plant, and a descriptive statement of the production processes (prescribed by regulations in Title 27, Code of Federal Regulations, Part 201.147, 149, and 153, respectively),

2. the firm's organizational documents (prescribed by 27 CFR 201.148),

3. the registration of the stills (prescribed by 27 CFR 201.150), and

4. a statement of title to the distillery and to the equipment used for the production of spirits (for lien purposes prescribed by 27 CFR 201.151 and 152).

All distilled spirits plants must also comply with the requirements of the National Environmental Policy Act and the Federal Water Pollution Control Act. Under these laws, every person intending to operate a distilled spirits plant must file with ATF information concerning the environmental impact of the proposed plant. This is done by filing ATF Form 4871 (1740.1), Environmental Information, and ATF Form 4805 (1740.2), Supplemental Information on Water Quality Considerations. From the information provided on these forms and on the permit application, ATF will determine whether the applicant must also obtain state certification that the proposed distilled spirits plant will comply with any applicable water quality standards. In general, this state certification is required whenever the activity of the proposed plant may result in a discharge of waste into any navigable waters of the United States.

The producer is responsible for denaturing the ethanol through the two formulas that are available from ATF for denaturing ethanol for authorized uses. The resulting material may be distributed through retail outlets.

One such completely denatured formula--CDA 19--is as follows: to every

100 gallons of ethanol of not less than 160^{o} proof add
4.0 gallons of methyl isobutyl ketone and
1.0 gallons of either kerosene, deodorized kerosene, or gasoline.

For use as an automobile or supplementary fuels, three specially denatured formulas are authorized--SDA 1, SDA 3-A and SDA 28-A. However with these formulas, the alcohol may not be generally distributed, because the potential exists for it to be converted illegally for beverage use.

Formulas SDA 1 and 3-A authorize the addition of 5 gallons of wood alcohol or methyl alcohol (methanol) to every 100 gallons of not less than 185 proof ethanol.

Formula SDA 28-A specifies the addition of 1 gallon of gasoline to every 100 gallons of not less than 185 proof ethanol.

Other formulas may be considered for denaturing purposes as long as the final article renders the alcohol unusable and unrecoverable for beverage use.

In addition, the security of the distilled spirits must be maintained, must be physically safeguarded. Too, the distilling system must be continuous and constructed in a manner which will prevent the unauthorized removal of the spirits. In short, the spirits are subject to continuous ATF control and supervision until the spirits are denatured, removed in bond to other bonded premises, or taxes are paid.

A distiller who fails to conduct business in accordance with all related laws and regulation is subject to penalties, fines and/or imprisonment.

4. Environmental

Each ethanol production plant must abide by appropriate state and national environmental regulations. Potentially adverse environmental impacts may result from the boiler operations and from the improper handling of cooling and process water, of wet stillage, and of "bad" batches. These impacts, however, can be virtually eliminated by implementation of known technologies in the total plant design.

a. Air emissions

Air emissions would primarily result from the boiler operations. On-farm ethanol production facilities may be impacted to only a very limited extent by state regulations concerning air emissions. A perusal of a limited number of state regulations revealed that agriculture-specific regulations deal for the most part with open burning only.

Community and larger size production facilities would need to comply with local regulations concerning visible emissions, particulate matter, sulfur dioxide, and other regulated emissions. For the most part the type of air emission controls required would be dictated by the type of boiler fuel used.

Another potential air quality problem could arise from a faulty or improperly designed azeotrope distillation unit. The benzene, ethyl ether, or other substances commonly used for distillation present significant health hazards; thus, the careful and proper handling of these materials is mandatory.

Potential odor problems could result from improper or careless handling of stillage. If the stillage is to be dried, then provisions for complying with local regulations concerning odor need to be incorporated into the drying equipment design and operating procedures. If the stillage is to be fed wet, then operational procedures must be instituted that allow the feeding operation to comply with the appropriate regulations regarding odor.

b. Water quality

Potentially there could be adverse local impacts on water quality resulting from plant cleanup operations, the occasional disposal of batches ruined by contamination, and the handling and feeding of wet stillage.

State regulations concerning feedlots and the land disosal of wastes, in particular, their disposal on frozen land, would direct these activities. Small scale on-farm units could potentially dispose of "bad" batches by land disposal, although certain states do prohibit land disposal of wastes on frozen ground.

The larger size plants would need to provide adequate wastewater treatment, including sufficient capacity to handle occasional contaminated products as well as the routine process and cooling water, as required by federal and state environmental regulations.

c. Solid waste

Solid waste disposal may be a relatively minor consideration except for those plants using coal or biomass boiler fuels. For these plants, disposal of ashes must be included in the plant design to prevent problems such as those due to leaching.

SUMMARY

V. RAW MATERIALS

Ethanol may be produced from a variety of farm crops and residues. Each potential feedstock needs to be assessed in terms of its suitability, availability, potential ethanol yield, cost, and by-product credit.

Suitable Feedstocks

Feedstock suitable for use for ethanol production by fermentation must contain sugars, starches, or cellulose that are readily convertible to fermentable sugars. Feedstocks can be roughly classified into three groups--those containing predominately sugars, starches or cellulose:

sugars: sugar beets, sugar cane, sweet sorghum, ripe fruits
starches: grains, potatoes, Jerusalem artichokes
cellulose: stover, grasses, wood, straw, paper pulp

Only farm crops and wastes containing starches or sugars will be considered as potential feedstocks in this study. Suitable industrial agricultural wastes such as whey will not be considered. Cellulose conversion will not be considered as the conversion process is still in the developmental stage.

Surplus and damaged grains, culls, and crop wastes are unlikely to be a continuous and dependable ethanol source. Such materials would provide uncertain annual quantities of ethanol at variable costs. Designing a production plant that would efficiently use only these materials under these circumstances would be difficult.

The by-product associated with each feedstock may be a viable commercial material, usually livestock feed or fertilizer. When feed grains are utilized as the feedstock, the resulting by-product stillage is a high protein feed. The market for the other stillage by-products is less well established. Experimental work is being carried out on the extraction of edible protein from the grain by-products. By-products are discussed in greater detail in Chapter VI.

Feedstock Availability

A major consideration in evaluating the potential for ethanol production from agricultural products is the present availability of feedstocks. With the exception of very small amounts of the feedstocks being utilized by the beverage industry, very little of the potential feedstocks are used in alcohol production. Statistics showing current U.S. production and dispersal of the most frequently mentioned ethanol feedstocks indicate that much of the present production is committed to feed, food, industrial uses, and exports.

Any assessment of potential feedstock that examines only the total U.S. production can be misleading. Major regional variations in the production of the potential feedstocks exist. This has implications for the quantities of ethanol that could be produced in an area and also for the type of ethanol production facilities that would be appropriate. In Table V-4, the production of major feedstocks by region is shown.

Nearly ninety percent of the small grains are produced in the Cornbelt, Lake and Great Plains states. Potatoes are grown primarily in the Western states and to a lesser extent in the Lake and New England states. Sugar cane production is limited essentially to the Southeastern region and Hawaii. Sugar beet production is somewhat more widespread with 52 percent of the production in the Western states and 27 percent in the Lake states. Sweet sorghum is grown to a very limited extent at present, but the feasibility of growing it at a variety of sites is being investigated since its potential alcohol production per acre of land is potentially greater than that from the grain crops.

The vast majority of the present production of feedstocks are committed. To produce ethanol then would mean changes in cropping patterns such as increases in production, shifts in utilization, and changes in crop choices. Increased production of the most efficient feedstocks could be anticipated if ethanol fuels prove feasible. Two such potential feedstocks--sweet potatoes and sweet sorghum--are frequently mentioned. Increased production of sweet potatoes could be anticipated in particular in the Southeastern region. Sweet sorghum production capabilities are being evaluated presently in test plots throughout the country (Lipinsky, et al. 1979). Both show great potential for high yields of ethanol per acre.

Potential Ethanol Yield

The quantity of ethanol that can be produced is dependent on the carbohydrate content of the feedstock (see Table V-5). On the basis of the number of gallons of ethanol per ton of feedstock, wheat, corn and the other small grains look most promising. However, a most useful comparison of potential feedstock may be that based on the quantities of alcohol that could be produced per acre.

Typical values of feedstock yield per acre are given for 1977 in Table V-6. From these values, the numbers of gallons of ethanol per acre are calculated, assuming the average fermentable content. On this basis, corn is the most promising of the small grains with a yield of 235 gallons per acre, for a yield of 100 bushels per acre. The other small grains are much less productive on this basis.

The most promising feedstocks are those containing sugar with sugar cane, sweet sorghum, and sugar beets yielding 555, 500, and 412 gallons per acre, respectively. In assessing these feedstocks, it must be kept in mind that only very limited areas of the U.S. have climatic conditions suitable for growing sugar cane. Sweet sorghum production is presently quite limited. Experimental work is being conducted to assess its potential (Lipinski, 1979).

Potatoes, too, produce greater quantities of ethanol per acre than does corn. For a yield of 261 hundredweight per acre, a production of 299 gallons per acre would be anticipated. (Jerusalem artichokes are mentioned frequently as a potential feedstock, but its present production is limited.)

Feedstock Cost

The feedstock cost per gallon of ethanol for most of the feedstocks can be calculated readily from market prices. Throughout the discussion of feedstock prices, it must be kept in mind that the prices used for comparison purposes are those paid for the feedstock for an alternative well-established use, not for their use in fuel ethanol production. The only prices available for use in ethanol production are those for beverage production which uses only top quality grain.

For purposes of estimating feedstock costs per gallon, an average feedstock price was used in conjunction with the average ethanol yield per unit of feedstock. On this basis, the least expensive feedstocks are grains, with grain sorghum, rye, and corn, having the lowest values at $1.07-1.14 per gallon. Wheat is somewhat more expensive at $1.36 (Table V-6).

Although sweet sorghum appears to be the least expensive feedstock at $0.44 per gallon, this value is based on the cost of production only (Nathan, 1978). No official statistics are maintained on sweet sorghum and no quoted prices were available.

Although potential alcohol production per acre was much higher for sugar beets and cane, the costs per gallon, $1.43 and $1.56, respectively, are comparable to that for wheat.

Net Feedstock Cost

In order to obtain a net feedstock cost per gallon, not only must the feedstock costs be considered, but the value of the distillers by-product must also be taken into account. As the values of the distillers by-products from grain are generally higher than those for the sugar crops, the net feedstock values for the grains are lower compared to the sugar crops. The value of the wet stillage must be estimated on the basis of the specific farming situation. Market prices are quoted for distillers dried grains (DDG) and distillers dried grains plus solubles (DDGS), although the value to the farm or local cooperative group may vary a great deal from the quoted market price. The by-products, their prices and credits, are discussed in greater detail in Chapters VI and VIII.

Ethanol may be produced from a variety of farm crops and wastes. The suitability of each type of feedstock may be assessed in terms of its calculated yield of ethanol, its availability by season and region of the U.S., and by its cost.

A. Types of Feedstock

Feedstock suitable for use for ethanol production via fermentation must contain sugars, starches, or cellulose that may readily be convertible to fermentable sugars. Feedstocks can be roughly classified into three groups--those containing predominately sugars, starches, or cellulose, as shown below.

sugars:	sugar beets, sugar cane, sweet sorghum, ripe fruits
starches:	grains, potatoes, Jerusalem artichokes
cellulose:	stover, grasses, wood

Only farm crop and waste substances containing starches or sugars as potential feedstocks will be considered in this study (cellulose conversion at this time is still in the developmental stage). Thus grains, sugar beets, sweet sorghum, potatoes, sweet potatoes, sugar cane, and fruit are discussed. Suitable industrial process wastes such as cheese whey are excluded. The fermentation and distillation processes for both starch and sugar feedstocks are essentially identical. Their variations occur in storage requirements for the feedstock, the preparation of the fermentable sugar from the raw feedstock, and the type of by-product produced.

The type of feedstock used has implications both for feedstock storage and in length of time during the year than an ethanol production plant could reasonably be expected to operate. Storage of any of the small grains would be the same whether they were to be used for feed or for alcohol production, i.e., moisture content, etc. would need to be controlled in order to prevent deterioration.

Sweet sorghum, sugar cane and sugar beets have a short storage life in their harvest form. Traditionally, the sugar industry has extended its processing season by extracting and storing the sugars in the form of molasses. The storage life of the feedstock is then considerably lengthened. Potatoes will be assumed to have a six-month storage period prior to the start of any significant deterioration in their sugar/starch content.

Overripe or damaged fruits would have an extremely short storage life and would need to be processed quickly. However, alcohol production from these materials would aid in alleviating their disposal problem.

Variations in the ethanol production process occur in the early production stages. After the initial preparation of the solution of the fermentable sugars, the process is essentially the same regardless of the feedstock. For the sugar containing feedstock, the initial production step involves crushing or grinding the materials and extraction of the sugar with steam or water. For the starch containing feedstocks, the first step in the fermentation requires the conversion (hydrolysis) of the starch via an enzymatic process to fermentable sugars. Their complete production process is described in greater detail in Chapter IV.

The average composition of some of the possible feedstocks are shown in Table V-1. Only the carbohydrate component of the feedstock is utilized by the fermentation process; all other components remain in the distillers by-product.

Four products result from the fermentation of the raw materials--ethanol, distillers by-product, carbon dioxide, and water. The relationships of these substances to that of the starting materials have been calculated and are shown in Table V-2. Difference in the initial starch (or sugar) and moisture content of the raw materials will result in variations in the quantities of products produced.

The by-product associated with each feedstock may be a viable commercial material, usually livestock feed or fertilizer. When feed grains are utilized as the feedstock, the resulting by-product stillage is a high protein feed. For example, spent grains and distillers grains have been marketed for a number of years by the beverage industry. The market for the other stillage by-products of the feedstock is less well established. Experimental work is currently being carried out on the extraction of edible protein from the grain by-products. By-products are discussed in greater detail in Chapter VI.

B. Availability of Feedstock

A major consideration in evaluating the potential for ethanol production from agricultural products is the present availability of feedstocks. With the exception of very small amounts of the feedstocks being utilized by the beverage industry, very little of the potential feedstocks are used in alcohol production. Current U.S. production and dispersal of the most frequently mentioned ethanol feedstocks have been compiled and are shown in Table V-3. Much of the present production of the two major small grains, corn and wheat, are committed to feed, food, industrial use, and exports.

Consider, for example the quantities of ethanol that could be produced if all the 1976 (the latest year for which complete data are available) ending stocks of all small grains were converted to ethanol. Assuming 2.5 gallons per bushel, the 2,380 million bushels of small grains (excluding rice) would convert to a total of 6.0 billion gallons of 200 proof ethanol. For comparison, the U.S. domestic demand for motor gasoline in the month of January 1976, was 8.3 billion gallons. However, it should be pointed out that there are tremendous year-to-year variations in ending stocks. The 1975 ending stocks were about one half those of 1976 while those for 1974 were only one third of that for 1976. For 1974 then, the quantity of alcohol that could have been produced from these stocks would have been reduced to 2.0 billion gallons.

Table V-1. Average composition of possible feedstock for ethanol production

	Water	Protein	Fat	Carbohydrates Fiber	Carbohydrates N-free extract	Mineral matter	Ca	P	N	K
	(Percent)									
Sugarbeet	83.6	1.6	0.1	1.0	12.6	1.1	0.04	0.04	0.26	0.25
Molasses-beet	19.5	8.4	0	0	62.0	10.0	0.05	0.02	1.34	4.77
Artichoke tubers	79.5	2.0	0.1	0.8	15.9	1.7	--	0.06	0.32	0.41
Cassava roots	67.4	1.1	0.3	1.4	28.8	1.0	--	0.04	0.18	0.33
- dried	5.6	2.8	0.5	5.0	84.1	2.0	--	--	0.45	--
Potatoes, tuber	78.8	2.2	0.1	0.4	17.4	1.1	0.01	0.05	0.35	0.48
Sugar cane	76.8	1.0	0.8	6.8	13.4	1.2	--	0.04	0.16	0.37
- molasses cane or blackstrap	26.6	3.0	0	0	61.7	8.6	0.66	0.08	0.48	3.67
Sweet potatoes	68.2	1.6	0.4	1.9	26.7	1.2	0.03	0.04	0.26	0.38
Corn, dent no. 3	16.5	8.9	3.8	2.0	67.5	1.3	0.02	0.26	1.42	0.28
Milo	11.0	10.9	3.0	2.3	70.7	2.1	0.03	0.28	1.74	0.35
Rice	12.2	9.1	2.0	1.1	74.5	1.1	0.04	0.25	1.46	--
Rye	10.5	12.6	1.7	2.4	70.9	1.9	0.10	0.33	2.02	0.47
Wheat, hard winter southern plains	10.6	13.5	1.8	2.8	69.2	2.1	0.05	0.42	2.16	--
Raisins, cull	15.2	3.4	0.9	4.4	73.1	3.0	--	--	0.54	--

Source: Morrison, Frank B., Feeds and Feeding, Abridged, Ninth edition. The Morrison Publishing Co., 1961.

Table V-2. Input-output relationships for converting selected raw materials to ethanol

Item	Corn	Grain sorghum	Wheat	Potatoes	Sugar beets
Input					
Unit	bu	bu	bu	cwt	ton
Weight per unit	56	56	60	100	2,000
Moisture content (percent)	13	13	13	78	75
Output (yield) per unit in percent					
Ethanol	30.7	31.8	30.2	8.6	8.2
Distillers by-product	33.0	30.9	33.8	6.9	8.9
Carbon dioxide	29.3	30.3	28.8	8.2	7.9
Water	7.0	7.0	7.2	76.3	75.0
Total	100.0	100.0	100.0	100.0	100.0
Output (yield) per unit in weight (lbs)					
Ethanol	17.2	17.8	18.1	8.6	164.3
Distillers by-product (dry)	18.5	17.3	20.3	6.9	178.5
Carbon dioxide	16.4	17.0	17.3	8.2	157.2
Water	3.9	3.9	4.3	76.3	1,500.0
Total	56.0	56.0	60.0	100.0	2,000.0
Conversion rate, gallons ethanol per unit 1/	2.6	2.7	2.74	1.3	24.9

1/ See Table V-5.

Table V-3. Feedstock supply and disappearance, 1976

	Supply					Disappearance							Put under support	
	Beg. Stocks	Produc-tion	Imports	Total	Used on farms where produced	Food	Seed	Industry Feed	Total	Exports	Total Disap-perance	Ending Stocks	Quantity	Percent of Production
	(million units)													
Small Grains														
Corn (bu.)	399	6,266	3	6,668	2,219	---513---		3,587	4,100	1,684	5,784	884	276	4.4
Grain sorghum (bu.)	51	720	-	771	207	-----6---		428	434	246	680	91	11.8	1.6
Wheat (bu.)	665	2,142	3	2,810	104	553	92	103	748	950	1,698	1,112	495	23.0
Rye (bu.)	4.4	15	0.2	19.6	3.6	3.7	4.7	6.7	15.1	0.04	15.2	4.4	0.1	1.0
Oats (bu.)	205	546	1	752	353	----88---		489	577	10	587	165	4.5	0.8
Barley (bu.)	128	372	11	511	98	---158---		161	319	66	385	126	18.7	5.0
Rice (cwt.)	36.9	115.4	.1	152.6	641	29.2		13.5	42.7	65.6	108.3	40.5	23.4	20.2
Potatoes														
White (cwt.)		357.7		6.6 1/										
Sweet (cwt.)		13.4		1.3 2/										
Sweet Sorghum 3/	In 1973-1975, the area harvested was less than 1,620 acres with yields of 84-209 tons per acre													
Sugar beets (tons)		29.4												
Sugar cane		28.1				26.9	1.2							

1/ 1975 Data: Used on farms where produced for seed, feed and household use. Shrinkage and loss 22.2 million cwt.

2/ 1975 data. Used on farms where produced. Shrinkage and less of 0.7 million cwt.

3/ No official statistics.

Source: United States Department of Agriculture, Agricultural Statistics, U.S. Government Printing Office. Washington, 1977 and 1978.

The major grain used on farms where it is produced is corn. In 1976, over one-third of the corn produced was used on the farms where it was grown. If one half of this quantity or 1,110 million bushels were to be converted to ethanol, at a rate of 2.5 gallons per bushel, then 2.8 billion gallons of 200 proof ethanol could potentially be produced. For comparison, 3.5 billion gallons of gasoline were used for crop production and livestock operations in 1978 (FEA/USDA, 1979).

Assessment of potential feedstock by examining the total U.S. production only, can be misleading, as there are major regional variations in the production of the potential feedstocks. This has definite implication for the quantities of ethanol that could be produced in an area and also for the type of ethanol production facilities that would be appropriate. In Table V-4, the production of major feedstocks by region is shown.

Nearly ninety percent of the small grains are produced in the Cornbelt, Lake and Great Plains states. Potatoes are grown primarily in the Western states and to a lesser extent in the Lake and New England states. Sugar cane production is limited essentially to the Southeastern region and Hawaii. Sugar beet production is somewhat more widespread with 52 percent of the production in the Western states and 27 percent in the Lake states. Sweet sorghum is grown to a very limited extent at present, but the feasibility of growing it at a variety of sites is being investigated, since its potential alcohol production per acre of land is potentially greater than that from the grain crops.

Potato production is classified by season, and over 88 percent of the production is classified as fall production. The Western states lead the nation with 60 percent of the total production. The Lake states and New England produce another 12 percent and 9 percent, respectively. Only in the Southeastern region is the contribution of spring potatoes high with respect to the total produced in that region. Of the total sweet potato production of about 12 million hundredweight, nearly 80 percent was grown in the Southeastern region.

The vast majority of the present production of grains are committed. To produce ethanol then would mean changes in cropping patterns such as increases in production, shifts in utilization, and changes in crop choices. Increased production of the most efficient feedstocks could be anticipated if ethanol fuels prove feasible. Two such potential feedstocks--sweet potatoes and sweet sorghum--are frequently mentioned. Increased production of sweet potatoes could be anticipated in particular in the Southeastern region. Sweet sorghum production capabilities are being evaluated presently in test plots throughout the country (Lipinski et al., 1979). Both show great potential for high yields of ethanol per acre.

C. Potential Ethanol Yield

In addition to consideration of the quantities of feedstocks available, the conversion rates of these feedstocks must be incorporated in the assessment of potential for ethanol production. Conversion rates for the feedstock

Table V-4. Regional production of potential feedstocks, 1977

	Corn	Milo	Wheat	Oats	Barley	Rice	Potatoes Winter	Potatoes Spring	Potatoes Summer	Potatoes Fall	Sweet Potatoes	Sugar beets	Sugar cane
	10^6 bu					10^6 cwt.					10^6 T		
New England	0	0	2	2	0	0	0	0	0	31	0	0	0
Mid Atlantic	208	0	22	35	12	0	0	0	3	18	1	0	0
Southeast	373	22	73	18	9	56	1	8	5	0	9	0	33
Cornbelt	3,462	68	259	142	2	1	0	0	2	4	0	1	0
Lake States	1,077	0	166	257	56	0	0	0	3	40	0	7	0
Great Plains	1,090	662	1,044	270	137	23	0	1	2	23	1	5	2
Western	136	36	462	20	199	18	1	14	6	187	1	13	0
Hawaii	0	0	0	0	0	0	0	0	0	0	0	0	20
Alaska	0	0	0	0	0	0	0	0	0	0	0	0	0
U.S. Totals	6,346	788	2,026	744	415	98	2	23	21	303	12	26	55

Source: U.S. Department of Agriculture, Agricultural Statistics, U.S. Government Printing Office, Washington, 1978.

being considered here are shown in Table V-5. The quantity of ethanol that can be produced is dependent on the carbohydrate content of the feedstock. On the basis of the number of gallons of ethanol per ton of feedstock, wheat, corn and the other small grains look most promising. However, a more useful comparison of potential feedstock may be that based on the quantities of alcohol that could be produced per acre.

Typical values of feedstock yield per acre are given for 1977 in Table V-6. From these values, the numbers of gallons of ethanol per acre are calculated, assuming the average fermentable content. On this basis, corn is definitely the most promising of the grains with a yield of 214 gallons per acre given a yield of 90.8 bushels per acre. The other small grains are much less productive on this basis.

The most promising feedstocks are the sugar-containing ones with sugar cane, sweet sorghum, and sugar beets yielding 555, 500 and 412 gallons per acre, respectively. In assessing these feedstocks, it must be kept in mind that only very limited areas of the U.S. have climatic conditions suitable for growing sugar cane. Sugar beets have been successfully cultivated in four fairly distinct climatic and geographic areas in the United States: the north central states, the Great Plains and Red River Valley, the mountain states and the Imperial Valley in California. However, production is limited in some areas by certain pests and plant diseases. Nematodes are the major sugar beet pests. Sweet sorghum production is presently quite limited. Experimental work is being conducted to assess its potential (Lipinski, 1979).

Potatoes, too, produce greater quantities of ethanol per acre than does corn. For a yield of 261 hundredweight per acre, a production of 299 gallons per acre would be anticipated. Jerusalem artichokes are mentioned frequently as a potential feedstock, but its present production is limited.

In order to completely assess the potential feedstock, one factor remaining to be considered is the cost of these various feedstocks.

D. Cost of Feedstock

The feedstock cost per gallon of ethanol for most of the feedstocks can be calculated readily from market prices. Throughout the discussion on feedstock prices, it must be kept in mind that the prices used for comparison purposes are those paid for the feedstock for an alternative well-established use, not for their use in fuel ethanol production. The only prices available for use in ethanol production are those for beverage production which uses only top quality grain.

For purposes of estimating feedstock cost per gallon, an average feedstock price was used in conjunction with the average ethanol yield per unit of feedstock. These estimates were based on a 15-year average (1963-77) of average prices paid to farmers, converted to a 1979 dollar basis by using the GNP price deflator. The values so calculated are shown in Table V-6.

Table V-5. Quantity of ethanol obtainable from various agricultural feedstocks

	Probable commercial yield of 199 proof ethanol			
	Per bushel		Per ton	
	Fermentable content		Fermentable content	
	Average	High	Average	High
	gallons			
Corn	2.35	2.62	84.0	93.6
Grain Sorghum	2.22	2.70	79.5	96.4
Wheat	2.57	2.74	85.0	91.4
Rye	2.20	2.54	78.8	91.0
Oats	1.02	1.05	63.6	66.8
Barley	1.90	2.05	79.2	85.5
Rice	1.79	2.21	79.5	98.2
Potatoes	0.69	0.79	22.9	26.3
Sweet Potatoes	0.94	1.29	34.2	46.6
Yams	0.75	1.00	27.3	36.6
Jerusalem Artichokes	0.60	0.75	20.0	25.0
Sugar Beets	-	-	22.1	24.9
Sugar Cane	-	-	15.2	17.3
Sweet Sorghum	NA	NA	NA	NA
Apples	0.35	0.38	14.4	15.7
Peaches	0.28	0.37	11.5	15.3

NA - Not available.

Source: U.S. Department of Agriculture, Motor Fuels from Farm Products, Miscellaneous Publication No. 327, Washington, D. C. December 1938.

Table V-6. Average feedstock cost per gallon of ethanol

Feedstock	Typical avg. yield/ acre 2/ (range)	Average conversion rate gal/T 3/	Gal/ acre	Avg. 1963-1977 price paid to farmers $(1979)/unit	$/gal
	(1977)				
Corn	90.8 (29-116)	84.0	214	2.69/bu	1.14
Grain sorghum	56.2 (16-80)	79.5	125	2.40/bu	1.08
Wheat	31.0 (22-72)	85.0	79	3.46/bu	1.36
Rye	24.5 (16-31)	78.8	54	2.36/bu	1.07
Oats	55.6 (35-70)	63.6	57	1.46/bu	1.43
Barley	43.8 bu (27-76)	79.2	83	2.35/bu	1.24
Rice (wt. avg. long, med. & short grain)	44.12 cwt	79.5	175	11.44/cwt	2.88
Potatoes, white	261 cwt	22.9	299	4.98/cwt	4.35
Potatoes, sweet	111 cwt	34.2	190	9.78/cwt	5.72
Sugar beets	20.6 T	22.1	412	31.58/T	1.43
Sugar cane	36.5 T	15.2	555	23.68/T	1.56
Sweet sorghum 1/	3.24 T/ac	NA	500	NA	.44 4/

1/ Lipinski, E. S., 1979

2/ USDA Agricultural Statistics, 1978.

3/ USDA, Motor Fuel from Farm Products, Misc. Publication 327, December 1938.

4/ Based on estimates production cost of $220 per acre (Nathan, 1978).

The cost per gallon of grain feedstocks was calculated using these factors. Based on these factors, the least expensive feedstocks are grains with grain sorghum, rye and corn, having the lowest values at $1.07-1.14 per gallon. Wheat is somewhat more expensive at $1.36.

Although sweet sorghum appears to be the least expensive feedstock at $0.44 per gallon, this value is a cost of production (Nathan, 1978). No official statistics are maintained on sweet sorghum and no quoted prices were available as sweet sorghum production is quite limited.

Although potential alcohol production per acre was much higher for sugar beets and cane, the costs per gallon, $1.43 and $1.56, respectively, are comparable to that of wheat.

In order to obtain a net feedstock cost per gallon, not only must the feedstock costs be considered, but the value of the distillers by-product must also be taken into account. As the values of the distillers by-products from grain are generally higher than those for the sugar crops, the net feedstock values for the grains are lower compared to the sugar crops. The value of the wet stillage must be estimated on the basis of the specific farming situation. Market prices are quoted for distillers dried grains (DDG) and distillers dried grains plus solubles (DDGS), although the value to the farm or local cooperative group may vary a great deal from the quoted market price. The by-products, their price and credit, will be discussed in greater detail in Chapter VI and VIII.

Below-grade grains, crop culls, and agricultural wastes such as overripe fruits have been suggested as possible inexpensive feedstocks for ethanol production. However, reliable estimates of the quantities of these materials available and their frequency of availability are unobtainable. In a few cases, these materials may be centralized, but for the most part it is believed they are not. Too, if damaged materials are to be utilized as feedstocks, whether occasionally or regularly, facilities for sterilizing the materials must be incorporated into the plant design. Sterilization is required in order to prevent the contamination of the sweet wort with undesirable organisms that might adhere to the materials and affect ethanol production.

Surplus and damaged grains, culls, and crop wastes are unlikely to be a continuous and dependable ethanol source. Such materials would provide uncertain annual quantities of ethanol at variable costs. Designing a production plant that would efficiently use only these materials under these circumstances would be difficult.

SUMMARY

VI. BY-PRODUCT UTILIZATION

The by-product stillage from ethanol production is a thin slurry containing about ten percent solids. Most distilleries dry this product and market it as distillers dried grains with solubles (DDGS). The dried product is a well-known feed ingredient generally used by feed manufacturers.

There are disadvantages to the use of stillage:

- The weight of material which is transported consists mostly of water.

- Animals are limited in their ability to consume water.

- The wet product deteriorates rapidly and should be fed within one to two days to avoid large nutrient losses.

The major advantage of using stillage is the elimination of the costs for the equipment and energy used to process DDGS.

Dried grains can be transported economically over larger distances and are much simpler for feed manufacturers and farmers to handle.

The price of distillers dried grains with solubles will be less than the price of soybean meal because of its lower, 27 percent protein content compared to that of 44 percent for soybean meal. The price of DDGS will be determined by the prices of protein feeds such as soybean meal and energy feeds such as corn. Figure VI-1 shows the relationship between the prices of DDGS, corn, and soybean meal at Chicago during the past 10 years. These price relationships would indicate relative prices if DDGS were sold as a feed ingredient on the wholesale feed ingredient market. The current Chicago price of DDGS (January 1979) is about $145 per ton.

For use on farms, stillage would compete with other protein sources which the farmer might use. Few farmers can purchase and use bulk carloads of soybean meal or other protein ingredients. Farmers who purchase protein supplements from feed manufacturers pay about 50 percent above bulk wholesale soybean meal prices for the soybean meal component. For formulated rations, the wholesale price of soybean meal was increased by 50 percent above the Kansas City price to compare the value of stillage at the farm level.

Stillage would probably be limited to use in beef, dairy, and swine rations. Two major assumptions were made in formulating appropriate rations:

- Liquid in the ration should not exceed four times the weight of the solids content.

- Feeds were formulated to use stillage as a protein source rather than a source of energy except for the heavier steer finishing ration where supplemental protein is normally supplied by urea.

The value of stillage for various rations was:

Calves, 550 lb.	-	\$.066 - \$.083/gallon
Steers, 770 lb.	-	\$.04 /gallon
Dairy cows	-	\$.079 /gallon
Swine	-	\$.06 /gallon

With normal feeding practice the amount of stillage which could be consumed by one animal would be:

Calves, 550 lb.	-	6.3 gal/day
Steers, 770 lb.	-	9.2 gal/day
Dairy cows	-	7.2 gal/day
Pig, 60 lb.	-	1.2 gal/day

Table VI-9 shows the number of animals which would be required to consume the stillage produced by plants having capacities of 60,000 gal/year and 360,000 gal/year.

When stillage is used in the rations of high production animals it must be available every day. The texture and taste of stillage rations is very distinct and animals would reduce their consumption with frequent formula changes. Small farm stills which produce stillage intermittently would have to restrict its use to low production animals, e.g., dry cows, or provide refrigeration or other means of preservation.

Transportation costs will be high for stillage compared to other feeds because about 90 percent of a load is water.

Transportation costs for feed delivery trucks are now about \$1.00 per mile or \$2.00 per mile on a round trip basis. A five-ton load of stillage would have a value of \$84 when priced at \$.07/gal. On this basis, if a truck delivered the stillage a distance of 42 miles, the transport costs would be equal to the value of the stillage. Similarly, a 20-ton load would have a maximum delivery distance of 168 miles, i.e. at a distance of 168 miles the value of the stillage would be zero.

VI. BY-PRODUCT UTILIZATION

The two primary by-products obtained during the production of ethanol by fermentation of agricultural products are the residue, commonly utilized as an animal feed, and carbon dioxide.

A. Animal Feed By-product

1. Forms of Grain By-products

Distillery by-products from grain are a high quality ingredient for animal feed. Four products are commercially available and have been defined by the American Feed Control Officials.

> Distillers Dried Solubles is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing the thin stillage fraction and drying it by methods employed in the grain distilling industry. The predominating grain must be declared as the first word in the name (Proposed 1963, Adopted 1964).

> Distillers Dried Grains is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by separating the resultant coarse grain fraction of the whole stillage and drying it by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name (Proposed 1963, Adopted 1964).

> Distillers Dried Grains with Solubles is the product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at least 3/4 of the solids of the resultant whole stillage by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name (Proposed 1963, Adopted 1964).

> Condensed Distillers Solubles is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing the thin stillage fraction to a semi-solid. The predominating grain must be declared as the first word in the name (Proposed 1969, Adopted 1970).

Because of the high energy requirements for drying products such as distillers and brewers by-products there have been continuing efforts to utilize undried products. Various brewers have marketed wet grains within

reasonable distances of the brewery, primarily for feeding ruminants. The untreated distillers by-product (stillage) has presented greater difficulties because of its higher liquid content; distillers stillage is approximately 90 percent water compared to 70 percent water in brewers wet grains. The reason for this difference is that brewers remove as much of the liquid as possible from the solid feedstock after enzyme treatment and this liquid (wort) is then fermented. Distillers simply distill the alcohol out of the fermented solid-liquid mixture.

Distillers could remove the solids fraction from the stillage and sell a wet grain product, but a problem of disposing of the liquid would remain. Too, a significant loss of nutrients (particularly soluble protein) in the liquid fraction would occur.

The equipment and operating costs for drying stillage is high, but for large distillers the advantages of marketing a dry product (or condensed solubles) are enough to overcome the high production costs. The major advantages of dry products include the following.

- Microbial decomposition is prevented in dry products. Wet products decompose rapidly and must be fed within one to two days in warm weather. Some preservatives might be used to increase the allowable storage life, but insufficient research has been done to determine the types of preservatives and their overall economics. Refrigeration could be used to extend storage time, but operating costs would be high; however, refrigeration costs would be lower than drying costs.

- The transportation costs for marketing dry products are reduced by eliminating the transport cost for water.

- Feed manufacturers are usually better equipped to handle dry ingredients.

- Farmers are usually equipped to feed dry feeds rather than slurries.

2. Quantity of Animal Feed By-product

About 16 pounds of by-product (dry weight) are produced from each bushel of corn. About 6 pounds are realized per gallon of 200 proof alcohol.

If the by-product is not dried but utilized as stillage, then the same equivalent solid materials will be produced. The concentration of solids in the stillage will depend upon the operation of the cooking and fermenting process. In normal operations, about 30 gallons of mash will be used per bushel of grain. After removal of the alcohol, there will be about 27 gallons (224 lbs) of stillage containing about 16 pounds of solids. The quantity will be reduced slightly if some of the liquid from the stillage is set-back for use in a succeeding batch. The amount of liquid which may

be set back has not been accurately determined but may be as much as 50 percent of the liquid. A stillage can probably be produced which will be more concentrated than the normal stillage. With maximum (50 percent) set back there would be 14 gallons (116 lbs) of stillage with 12 percent solids per bushel of corn.

A large increase in fuel alcohol production would lead to a change in the supply of vegetable protein supplement available for animal feeds. A major increase in alcohol production, say to the point of utilizing one billion bushels of corn per year would increase the DDGS supply from the present 450,000 tons per year to 8,000,000 tons per year. Obviously this would have a significant effect on the supply and price of vegetable protein supplements. However, this diversion of corn would be equivalent to about 10,000,000 acres of corn production at about average yields. Such a diversion of corn supplies could change the relative corn-soybean acreages to reduce soybean supplies, and overall protein supplies might not be affected greatly.

Table VI-1 shows present overall vegetable protein supplement supplies from major sources. An additional 8,000,000 tons of DDGS would represent a very significant increase in that supply but a much smaller percentage of the overall supply.

3. Stillage as a Feed Ingredient

In spite of the advantages of dry products, stillage is probably the preferred form of disposing of by-products from small stills. The quantity of stillage should be small enough to allow it to be fed within a reasonable distance from the point of production.

Since stillage feeding has not been widely practiced, there is limited research or documented use-data on which to base recommendations for feeding from either nutritional, animal performance, or technical (handling) standpoints.

The Kentucky Agricultural Experiment Station (Wilford, 1944 and Garrigus, 1948) reported some research on stillage feeding during the 1940's. This research was directed toward maximum utilization of stillage rather than a most efficient use of its nutrient elements.

In general, the Kentucky recommendations were that adult beef animals should be limited to 40 gallons of stillage per day and swine to 4 gallons per day. Beyond these limits, urinary and other animal problems arose. When stillage is fed at these levels, animals are being forced to consume water at an above normal level and protein, particularly, is supplied in excessive amounts. In the discussion which follows later, it will be assumed that stillage will be fed at a level which will make the best economic utilization of its nutritional (chemical) elements, and under these conditions the normal animal intake of water will usually not be exceeded.

Table VI-1. Vegetable protein meal production

Material	Calendar or crop year	U.S. Production		
		Domestic consumption	Export	Total
		(1,000 T)	(1,000 T)	(1,000 T)
Corn Gluten Meal and Feed	78-79	1,038	2,031	3,069
Cottonseed Meal	1978	1,996	26	2,022
Distillers Dried Grain	78-79	496	---	496
Linseed Meal	1978	81	38	119
Peanut Meal	1978	89	---	89
Soybean Meal	1978	16,498	6,520	23,018
Sunflower Meal	78-79	198	---	198
TOTAL		20,396	8,615	29,011

Source: USDA, ESCS, Fats and Oils Situation.

Since water is normally considered a "free good," feeding trials do not normally report water consumption. A few reports have been found from which rough estimates of water consumption may be made.

A literature review by Leitch and Thompson (1944) reported studies by Crowther in which water-to-feed ratios of 3:1 for small weaned pigs to 1.75:1 for finishing weights. Quilany recommended a 3:1 ratio. Danish milk-grain rations, recommended in 1937, provided about a 2.5:1 liquid solid ratio for young pigs and 1.5:1 for finishing.

Barber, et al. (1965), reported that over the entire feeding period for swine a slurry containing a water-solids ratio of 3:1 gave equal results to a dry feed ration where hogs drank 2.4 pounds water per pound meal when furnished water ad lib.

Holmes and Robinson (1965) reported a water-feed ratio of 3.9:1 for a normal feed, but this decreased to 2.2:1 when dietary penicillin was added.

Brode and Rowell (1967) fed a 4:1 slurry which outperformed a dry feed with water ad lib.

The effects of temperature were not investigated in the above trials. Gardner and Sanders (1937) reported that nursing sows will consume about 18 to 20 kg of water per day and that temperature is not a significant factor.

Mount et al. (1971) fed a dry ration with water ad lib. The water to feed ratio increased slightly when temperatures rose from 7-12°C to 20°C from 2.6:1 to 2.7:1, but a further temperature rise to 30°C increased the ratio to 4.2:1.

Leitch and Thompson (1944) report on various trials of fattening steers which show water intakes of 2.70:1 to 3.81:1. There was considerable animal-to-animal variation.

Winchester and Morris (1956) calculated the water requirements for cattle of various types, ages, and conditions of feeding. They based water consumption rates at 3.15:1 at 40°F and 7.48:1 at 90°F.

Ittner, et al. (1962) fed yearling cattle a hay ration which produced about 1.5 pounds per day gain. The cattle consumed a water-feed ratio of 5.5:1.

Dairy cattle require a high water intake which is related to level of milk production. Most research reports were made before present production levels were reached. Brody et al. (1954), reported water consumption of 16.5 to 19.7 gallons per day at a temperature of 50°F for Holstein cows producing 34.3 to 45.5 pounds milk per day; at an air temperature of 17°F water intake varied from 15.8 to 18.6 gallons per day with production

of 30.4 to 35.7 pounds of milk per day. Total dry matter intake was not reported (only total digestible nutrients) but the water-feed ratio was probably about 4:1.

Owen, et al. (1968) reported a water-feed ratio of 4.8:1 for the first 8 weeks after calving.

Stillage and wet grains must be used in a relatively short time to avoid excessive microbial decomposition. Little research has been reported, but a recent publication by Stechley, et al. (1979) reports on the effect of storage on brewer's yeast slurry. Slurry was stored at 4^{o}, 21^{o} and $30^{o}C$ for 35 days. Storage at $4^{o}C$ showed small changes in chemical composition during the 5 week period. Storage at $21^{o}C$ ($70^{o}F$) showed significant changes in the first seven days; 15 percent of the dry matter was lost, and true protein dropped from about 30 percent to 20 percent (a 30 percent loss) on a dry-matter basis. At $30^{o}C$ the dry matter loss was about 16 percent and protein dropped from about 30 to 13 percent. Total crude protein increased slightly as dry matter decomposed, but the true protein was converted to ammoniacal form. The protein conversion would have little effect on ruminants, but it would be undesirable for monogastrics.

Miller (1969) evaluated the losses when distillers wet grains were ensiled. Dry matter losses ranged from 11 to 21 percent, but the loss of soluble carbohydrates was high in relation to other lower value fractions such as fiber. Removal of spoiled material which should not be fed was difficult.

The conclusion to be reached is that stillage and/or wet grains must be fed within one or two days to avoid significant nutrient loss or be given special treatment, probably refrigeration. Although this problem is not insurmountable, it will be a significant problem, particularly for the smaller farm size still which may not distill a batch every day.

Stillage or wet grains have a distinct odor and cannot be added to or removed from rations randomly without an adverse effect on feed consumption and animal performance. This will be a very important factor with dairy cattle. Also, with dairy cattle, the material may affect milk flavor; hence, it is probably best to feed just after, rather than shortly before, milking.

Possible physical forms of by-products which appear practical for small plants include:

- stillage which is probably the only practical form for disposing of by-products from farm stills,
- wet grains from medium size operations,
- condensed solubles from medium or large operations, and
- distillers dried grains or distillers dried grains with solubles from medium or large operations.

Wet grains which are 30 percent solids could be delivered greater distances, but again the economical delivery radius is limited.

4. Value of Distillers By-products

Historical prices for distillers dried grains exist, for they have been used for many years by commercial feed manufacturers. Table VI-2 shows January 1 and July 1 prices of corn, soybean meal, and distillers grains at Chicago for the past 10 years.

A linear regression analysis of the Chicago data yielded the following relationship of distillers grains price to the price of corn and soybean meal.

$$\text{Distillers grain price} = 16.28 + .439\ (\text{corn price}) + .356\ (\text{soybean meal price})$$

All prices are in dollars per ton. The standard error of estimate for the three constants are 16.28 ± 10.5, $0.439 \pm .14$ and $0.356 \pm .06$.

Figure VI-1 relates distillers grains and corn and soybean meal prices based upon the relationship obtained.

Stillage prices are not reported and published. Some beverage distillers have sold stillage at prices which are probably just about sufficient to cover the cost of handling and which would encourage farmers to use the product on a regular basis.

Due to constraints of storage and palatability (if stillage is not kept constantly in the rations of high production animals), small farm stills may have to dispose of the by-product by spreading it on land or feeding it, when available, to low production animals such as dry cows. Under these circumstances, the value of the by-product may be negative to slightly positive.

When a plant becomes large enough to distill every day, then the constant supply of stillage provides the opportunity to take advantage of its full nutritional value. If it can be delivered and fed every day with a holding time not exceeding 24 hours, then little nutrient loss will occur, and including it in the ration every day should eliminate its palatability problem.

The nutrient composition of stillage has not been extensively reported. For this analysis, it was assumed that for a given amount of solid material the composition of stillage will be the same as distillers dried grains with solubles (DDGS). Table VI-3 compares some important properties of DDGS with corn and soybean meal.

Table VI-2. Wholesale prices, dollars per ton, bulk, Chicago

	January 1			July 1		
	# Yellow corn	Soybean meal	Distillers grains	#2 Yellow corn	Soybean meal	Distillers grains
1979	80.00	194.60	141.00	108.60	218.30	151.10
1978	77.90	182.60	130.00	85.70	186.10	120.00
1977	88.60	209.70	140.00	78.60	184.70	140.00
1976	92.10	136.00	105.00	108.90	232.70	130.00
1975	118.70	139.80	107.50	100.30	124.30	103.00
1974	97.10	174.80	138.00	109.30	107.80	92.50
1973	55.00	189.10	100.00	85.00	306.60	138.00
1972	42.90	87.50	64.00	45.00	106.20	71.00
1971	56.40	85.90	70.00	54.30	88.00	67.00
1970	44.00	84.50	64.00	49.60	85.70	61.00

Source: Feed Market News, USDA, AMS.

Figure VI-1. Price relationships of DDGS, and stillage, to corn and soybean meal based upon Chicago historical prices.

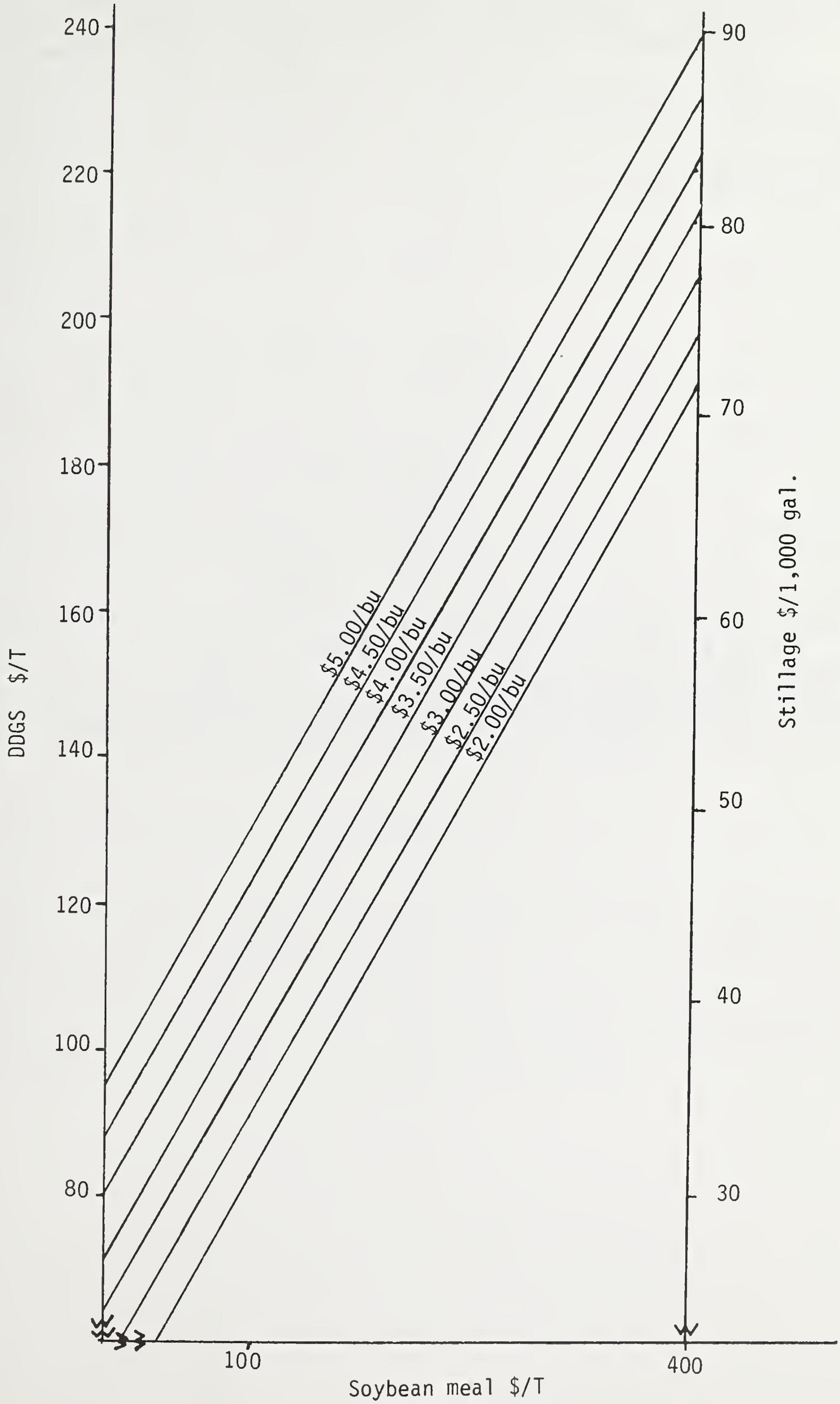


Table VI-3. Average nutrient compostion of DDGS, corn and soybean meal

	DDGS	Corn	Soybean meal
Dry matter, %	93	89	89
Digestible energy, K cal/kg	3568	3525	3350
Protein, %	27.2	8.8	44.0
Lysine	0.6	0.24	2.93
Methionine	0.6	0.2	0.7
Cystine	0.3	0.2	0.7
Crude fiber, %	9.1	2.2	7.3
Calcium, %	0.35	0.02	0.29
Phosphorous, %	0.95	0.28	0.65
Niacin, mg/kg	80	34	60
Pantothenic acid, mg/kg	11.0	7.5	13.3
Riboflavin, mg/kg	8.6	1.0	2.9

From: Nutrient Requirements of Swine, National Research Council, 1979.

Table VI-3 shows energy to be about equal for all three ingredients. DDGS has a lower protein content than soybean meal but would be considered a protein feed rather than an energy feed such as corn. The major deficiency of DDGS is its very low lysine content, but pure lysine, commercially available at rather reasonable cost, can overcome this deficiency.

The relatively high fiber content of DDGS will limit somewhat its use in poultry broiler and layer rations where very high energy levels are used to achieve maximum performance.

The level of major minerals, calcium and phosphorus, is higher in DDGS than in soybean meal.

Limiting and important B-vitamins levels in DDGS compare favorably with soybean meal.

5. Ration Formulation and Use of By-products

National Research Council (NRC) nutrient requirements were used to formulate rations for several important animal classes:

- beef steers of about 550 pounds,
- beef steers of about 750 pounds,
- dairy cows,
- swine on a growing ration, and
- pullets on a developer ration (only DDGS was considered)

The ration formulation used a least-cost linear program to determine the maximum price at which DDGS would replace soybean meal as the protein source. A total liquid constraint was imposed which would limit the moisture content of the ration to four pounds of water per pound of dry feed (solids). Nutrient factors for other constraints were selected to include those now being used by a medium-sized Kansas commercial feed mill (Blair Milling Co. of Atchison, Kansas).

The same feedmill furnished current prices for all ingredients except roughage, corn, soybean meal, and DDGS.

Selection of prices for roughages and corn was made based upon current (1979) farm prices. The price of soybean meal was taken as 50 percent higher than the current Kansas City bulk wholesale carlot price. Large farmers buying carloads of soybean meal would pay less than 50 percent over wholesale prices. Smaller farmers who purchase commercial protein supplements would pay about 50 percent over wholesale for the soybean meal component of the protein supplement. Other ingredients required to balance the ration were similarily priced at 50 percent over wholesale. Table VI-4 shows the prices used for all ingredients except DDGS.

Table VI-4. Ingredient prices used for formulation [1/]

Ingredient	$/kg	$/2,000 lb	Other
Brome hay	.055	50	
Corn stover	.0275	25	
Corn	.0982	89	$2.50/bu
Milo	.0869	79	3.95/cwt
Soybean meal	.3135	285	
Meat and bone meal	.396	360	
17% dehydrated alfalfa	.181	164	
Urea	.280	254	
Calcium	.0363	33	
Dicalcium Phosphate	.3383	307	
Salt	.0825	75	
Trace mineral mix	1.30		
Lysine	6.60		$3/lb
DL methionine	5.35		$2.43/lb
Vitamin mix	2.20		$1/lb

1/ Nonfarm ingredients priced at 50% over wholesale to reflect manufacturing and marketing costs of typical feed supplements.

After the linear programming had selected the level and price for DDGS and the major ingredients, the formula was checked against total nutrient requirements and a premix was formulated to supply the required levels of other ingredients such as vitamins A and D, salt, etc. The retail price of this premix was calculated for each ration.

Table VI-5 shows the nutritional constraints used in the linear program for each ration formulated. Selection of the type of energy constraint was arbitrary and based upon the practice of the Kansas feed mill. Urea was allowed only in the steer ration although some urea might be allowed in calf and dairy rations by some nutritionists. Stillage was not thought to be appropriate in the pullet rations because of handling and mixing problems. Ingredients considered in each formulation were those thought to be appropriate and likely to be used in a practical operating situation in the Midwest.

Table VI-6 shows the rations which were formulated for the ruminants including those components which would be incorporated in a supplement to be used with the farm supplied ingredients to meet the NRC nutritional requirements. The steer ration which allowed some nonprotein nitrogen (urea) to enter the ration does not need a natural protein supplement; hence, stillage can only be forced into the ration by lowering the price until it becomes competitive with corn as an energy source.

The replacement pullet ration uses some soybean meal but could be forced out entirely by lowering the price of DDGS even further.

The swine ration was stillage for all of the protein supplementation. Lysine supplementation is required, but the cost is not great. Because of the free fatty acid components of corn oil, high levels of DDGS or stillage in swine finishing rations would cause the same soft pork problem as has been observed with peanut meal supplements. It may be necessary to reduce the level of stillage in the later finishing phases, but the exact time and level will have to be determined from feeding trials. These formulas were restricted to the prefinishing phase.

The dairy ration should not contain enough stillage to give any problems with water intake. There is a slight possibility that feeding stillage a short time before milking could result in off-flavor milk. It should give no problems if fed just after milking.

6. Comparison with Other Recent Studies

A recently published study by Lipinsky *et al*. (1979) reported on the possible use of corn stover supplemented with DDGS and concluded that the best "fit" was for feeding lighter calves and that weight gains of 0.6 kg per day were feasible. The ration consisted of 2/3 corn stover and 1/3 DDGS. (The present study formulated for 0.9 kg per day which required some corn.)

Table VI-5. Nutrient constraints used in least cost formulation

Item	Units per ton dry solids	Ration				
		Calf 1/	Steer 2/	Dairy 3/	Swine 4/	Pullet 5/
TDN 6/	Kg	>720	>770			
Net Energy	M Cal			>1520		
Metabolizable Energy	M Cal					>2900
Digestive Energy	M Cal				>3380	
Fiber	Kg			>170		
Protein	Kg	110-130	110-130	140-160	>160	
NPN Protein 1/	Kg	0	<15	0	0	0
Lysine	Kg				> 7	> 11
Methionine	Kg				>2.3	> 4
Methionine + Cystine	Kg				>4.5	>7.5
Thiamine	g.				>1100	
Riboflavin	g.				>2600	
Pantothenic acid	g.					>10,000
Niacin	g.					>27,000
Calcium	Kg.	3.5-4.5	2.9-3.9	4.8-5.8	6-8	8-18
Phosphorous	Kg.	>3.1	>2.6	>3.4	> 5	> 4
Water		<4000	<4000	<4000	<4000	Used DDGS

1/ 250 Kg calf graining 0.9 Kg/day.
2/ 350 Kg steer gaining 1.3 Kg/day.
3/ 600 Kg cow producing 23 Kg/day.
4/ 20-35 Kg hog gaining 600 g/day.
5/ 0-6 week old replacement pullets.
6/ TDN = total digestible nutrients.
7/ NPN = non protein nitrogen

Table VI-6. Composition of rations formulated and price of stillage or DDGS quantity of ingredient per metric ton of dry solids fed

Ingredient	Calf	Calf	Steer	Dairy	Swine	Pullet
Brome hay	732		360	432		
Corn stover, kg		779				
Corn, kg		121	263	471	723	
Stillage, kg or,	4267	1833	4375	1786	3273	
Stillage, Gal or	1131	485	1159	473	867	
DDGS, kg (equivalent)	474	203	486	198	364	965
Soybean meal, kg						21
Dical. Phos., kg		7				
Limestone, kg			2	9		12
Salt, kg	2.5	2.5	2.5	2.5	2.5	2.5
Trace minerals, kg	.55	.55	.55	.55	.56	.55
Lysine, kg					4.23	4.67
Choline chloride, kg					.25	
Vitamin premix, kg	.55	.55	.55	.55	.25	1.39
Stillage price $/kg	.0174	.022	.010	.021	.016	-
Stillage price $/gal	.066	.083	.04	.079	.060	
DDGS price $/kg	.174	.22	.10	.21	.16	.11
$/2000 lb	158	200	110	191	145	100

Keinholz and Rossiter (1979) evaluated the possible use of DDGS in rations fed in Colorado. The analysis pointed out that in beef rations the best use will be for lighter weight calves. The suggested ration for calves contains slightly more roughage and less distillery by-product but does not state the goal for rate of gain. The study also points out that steer finishing rations utilize a "very substantial amount of nonprotein nitrogen" but did not include this factor in its recommendations.

The Colorado study emphasizes the need for further research before firm conclusions can be reached regarding the level allowable in swine finishing diets. It predicted that DDGS could be used at up to 20 percent, a rate slightly less than the amount (32 percent) assumed in the present analysis.

The dairy lactation ration in the Colorado study used more roughage and less concentrate than that of the present study, but the ratio of DDGS to grain was approximately the same. The Colorado analysis did not specify a milk production level.

The Colorado study recommended using DDGS in pullet developer rations along with some grain and alfalfa meal. (Other protein supplements, presumably soybean meal, were retained.) A layer ration was also included but performance goals were indicated. If the price of DDGS were low enough it could be used in major poultry rations such as broiler or layer rations, but production rates would be lowered due to the lower energy intake. It is probable that this use of DDGS would not be profitable overall.

7. Potential for Utilization of Stillage

The potential for stillage utilization is very site specific. Transport costs will be a major factor in assigning a value at the plant since the value at the farm is the one calculated in the formulation analysis above. If the plant is owned by the farmer, then no marketing costs would be incurred. If stillage incurred marketing costs, other than transportation, then the effective price is further reduced. Marketing and processing costs, excluding transportation, are generally about 33 percent of the retail price for manufactured feeds. Retailer margins are of course, less. A marketing margin of 10 percent should be reasonable for a plant which sold stillage at retail.

Transportation costs will be a major factor in determining the radius over which stillage might be utilized economically.

Stillage would have to be delivered by tank truck, and the quantities would be variable depending upon the size of customer. Loading and unloading times would be similar to that of other feed. Truck operating costs were obtained from two large feed manufacturers.

Table VI-7 shows major costs incurred by one feed manufacturer for a small fleet of trucks operating in Alabama in 1978. The miles per trip would be greater than for stillage since dry feed was delivered. Another Midwest feed manufacturer estimates current truck costs at $.95 to $1.00 per mile.

If truck operating costs are $1.00 per mile and a 20 ton (4,800 gal) load is assumed, then the cost per mile per gallon of stillage is 0.0002 per mile per gallon or 0.0004 per delivery mile (the truck must travel out and back). If stillage has a value at the farm of $0.075 per gallon, then the plant value drops to zero for a 188 mile delivery radius. (For a delivery distance of 18 miles, the value of the stillage is reduced by 10 percent to $0.068.) If the marketing cost, exclusive of transport, is 10 percent, then the maximum delivery radius is reduced to 170 miles.

8. Stillage Drying

Although the drying of stillage to DDGS requires large amounts of energy, it is a necessity for large plants which have little chance to dispose of large amounts of stillage within a reasonable radius.

Small plants which might consider using relatively simple drum dryers, such as those used in alfalfa dehydration, would use about 1,400 Btu per pound of water evaporated. If stillage were 10 percent solids, this would require about 75,000 Btu per gallon of alcohol. Obviously, this would be generally infeasible.

Larger plants, in the range of upward from one million gallons per year, can justify the investment in more efficient drying techniques such as vapor recompression evaporators. Their energy efficiency is improved sufficiently to allow dehydration to be feasible.

9. By-product Consumption and Animal Populations

The amount of marketable by-products, particularly stillage, will depend upon the local numbers and mix of animals. As shown in Table VI-6 ruminants, particularly calves and dairy cows, represent the most attractive outlet. Exact quantities utilized depend upon numbers of animals and their production levels. Larger amounts of stillage could be used in some cases by using stillage as an energy rather than a protein source, but its value will drop rapidly to compete with grain rather than protein sources such as soybean meal.

Some typical quantities of by-products which might be used by various kinds of animals are shown in Table VI-8.

Table VI-9 shows the number of animals which would be required to consume the stillage produced by 60,000 and 360,000 gallon per year stills. The number of animals required for the larger still, those ranging from 7,200

Table VI-7. Transportation costs for a typical feed mill operating 20-ton capacity trucks in 1978

Cost item		$/mile
Fixed expenses		.11
Labor		.50
Maintenance and repair	.14	
Tires	.03	
Fuel, oil, grease	.12	
Other variable	.04	
Total variable		.33
Total		.94

Table VI-8. Animal consumption of distillers by-products

Feed	Production rate	Kg feed/day	Lb feed/day	DDGS lb/day	Stillage, gal/day 10% solids	20% solids
Type of animal						
550 lb calf (hay ration)	2 lb/day, gain	6.2	13.7	5.8	6.3	3.1
770 lb steer	2.8 lb/day, gain	8.8	19.4	8.5	9.2	4.6
1,300 lb cow	50 lb/day, 3.5% milk	16.8	37.0	6.6	7.2	3.6
60 lb pig	1.3 lb/day, gain	1.5	3.3	1.1	1.2	.6
Pullet, age 3.7 weeks		.057	.13	.13	NA	NA
Pullet, age 7.5 weeks		.1	.22	.22	NA	NA

NA = not applicable.

Table VI-9. Number of animals required to utilize stillage*

	Size of still	
	60,000 gal/yr	360,000 gal/yr
	----------number of animals----------	
Type of animal		
550 lb calf	230	1,365
770 lb steer	155	931
1,300 lb cow	200	1,200
60 lb pig	1,200	7,200

* Based upon 300 days/year production.

pigs of 60 pound weight to 931 steers of 770 pounds weight, do not appear to present great problems for stillage disposal. Many large cattle feedlots could even use the stillage from a 1,000,000 gallon per year still.

10. Some Unique Problems of Stillage Utilization

Stillage will produce rations of unique physical form, odor and palatability. High production animals must be kept constantly on such rations to maintain the feed consumption levels required. Frequent interruption of supply would drastically reduce the value of the stillage; consequently, if frequent interruptions occur, perhaps due to shut down for maintenance, then it might be necessary to maintain refrigerated supplies for emergency use.

Rapid loss of nutrients due to microbial action will require that stillage holding time be limited; it should be fed within about 24 hours during summer months.

Handling and feeding stillage during very cold weather will present some new and unique problems because of freezing. Twice a day feeding will be necessary under many conditions where feed bunks are located outside in Northern regions.

Feed bunks will have to be capable of holding feeds containing large amounts of liquid. Concrete bunks would probably be adequate with some sealing at joints. The dry feed could be placed in the trough and then the stillage placed on top. It may be possible to mix roughage and stillage in the normal mixer-feeder wagons.

Slurry feeding equipment has been developed for swine feeding in Europe and should be available with little modification.

Stillage and wet distillers grains have not been defined by the American Feed Control Officials. This will be necessary before they can be widely marketed.

One potential use of condensed solubles was considered but not investigated. Liquid feed supplements for beef are becoming increasingly popular. Usually they are molasses-urea mixtures, but some natural protein would be preferred by many nutritionists. A few feed manufacturers are using substantial quantities of condensed solubles in their liquid feed formulations.

11. Other By-products

The foregoing discussion focused on grain distillers by-products. Although certain characteristics of the by-products produced from other feedstock differ, the analysis of their utilization would be analogous. Distinct properties of potato and sugar crop by-products are delineated below.

Potato Dry By-product

The by-product of potatoes should contain a higher ash content by a factor of at least 5 as compared to that of corn distillers grains. The protein content should be slightly less and the fiber content about equal to those for corn distillers grains. Amino acid data are not readily available. B-vitamin composition should be about the same since this originates from the yeast. Table VI-10 shows an estimated composition. Because of the lower protein, the material would have a lower value than DDGS.

Sugar Beet By-product

Sugar beet pulp is a well-defined commercial feed ingredient which is presently priced at Chicago at $130 per ton compared to $145 per ton for distillers dried grains. If the solubles were condensed, the price should be about the same as brewers dried yeast which is now priced at about $400 per ton basis Chicago; hence, the overall value of these by-products should be greater than that for grain by-products.

Sugar Cane By-products

The plant residue from sugar manufacture (bagasse) is of relatively low value; some is used for the manufacture of building board but most is used for boiler fuel. Its yeast residue could be recovered and should have the same value as other dried yeast.

Sorghum By-products

The plant residue may have a slightly higher feeding value than sugar cane but no nutritional data have been found. The yeast by-product would be valuable.

B. Carbon Dioxide

1. Quantity and Quality

Carbon dioxide is produced in about equal weights with alcohol during the fermentation process. One pound of carbon dioxide has a volume of 8.1 cubic feet per pound. A million-gallon-per-year still would, therefore, produce about 21,000 pounds of carbon dioxide per day having a volume of 170,000 cubic feet.

The gas from the fermentors would be relatively pure carbon dioxide (and water vapor) if the fermentors were relatively tight and would be suitable for many uses. Keeping a slight positive pressure inside the fermentor would exclude air.

Table VI-10. Estimated composition of potato distillers dried by-product

Element	Composition
	(%)
Water	10
Ash	9
Crude fiber	5
Ether extract	1
N-Free extract	53
Crude protein	22

2. Collection and Storage

As the gas is removed from the fermentor, it could be dried, compressed for storage, and used as a gas or frozen to form dry ice.

3. Utilization

Carbon dioxide is frequently used to preserve the quality, including color, of many agricultural products. Fresh fruits and vegetables are preserved in improved condition in limited oxygen atmospheres. The color of meat can be maintained in an inert gas atmosphere.

In the past, many beverage distilleries produced dry ice, but the advent of mechanical refrigeration equipment for transport equipment reduced the market for the product.

Today, most distillers vent the carbon dioxide to the atmosphere as it is uneconomical to process it. The utilization of carbon dioxide would be very site specific. The value of the product would probably be about equal to the costs of recovery.

SUMMARY

VII. GENERAL ETHANOL PRODUCTION PLANT CHARACTERISTICS

Facilities for producing ethanol by fermentation considered in this study were grouped according to process type and production capacity as follows:

Type	Ethanol Production Capacity
famer-built one-of-a-kind	2-40 gallon per hour of 160-190 proof
Factory built equipment package	20-50 gallon per hour of 160-190 proof
	150-700 gallon per hour of 190-200 proof

The smallest farm stills will use one tank for cooking and fermenting the mash. One batch will be processed about every three to four days. It will be distilled by pumping the mash through a stripping column to remove alcohol and water, and the mixture of alcohol and water vapor will then go to a rectifying column to concentrate the alcohol to 160-190 proof (80 to 95 percent alcohol). In systems in which the mash may be heated in the fermenting tank, only one column is needed. Such a system is frequently called a "pot still." The farm-built pot stills will be of varied designs, and it is impossible to define their efficiency and operating costs.

The recent interest in alcohol fuel production has caused many companies to consider producing pot stills. These will be produced on a small scale mass production basis and designs will be standardized. Their operating characteristics can or should then be defined or specified on the basis of operating tests. Few manufacturers are yet in a position to guarantee the operating characteristics of their equipment.

Larger farm stills will use one tank for cooking and three or more tanks for fermenting, and will distill every day. These units will probably be designed, manufactured, and sold as packaged units and will probably employ one or more persons full time for their operation. Their annual capacity will be in the range of 60,000 to 360,000 gallon of ethanol of 160 to 190 proof. Their by-product will be stillage.

Larger units of a 1,000,000 gallon or more per year annual capacity will be 24 hour per-day operations and should operate seven days per week if stillage is the by-product. If the by-product is dried, then continuous operation will not be as necessary. These industrial type units may be standard packaged or custom-designed plants.

The larger plants will probably produce the 200 proof ethanol which can be used for mixing with gasoline for gasohol. The larger plants might sell their by-product as stillage, but they will probably prefer to install dryers and market distillers dried grains.

Grains will be the normal feedstock for most ethanol plants in the near future. Plants which might use sugar crops such as sugar cane, sweet sorghum, or sugar beets will probably be designed to use grains also during the season of the year when the sugar crops are not available. The availability of waste products such as cull potatoes and fruits is too erratic to be practical in most cases.

If ethanol plants are to make a significant contribution to the liquid fuel supply, they will have to use gas, coal or other solid fuels such as wood or crop residues. The use of gas is questionable in the long term. Coal is generally available, and furnaces and boilers to utilize it are, also, readily available. Furnaces and boilers to utilize wood are available, but there are few manufacturers of the equipment. The use of crop residue as fuel will be difficult in the next few years until handling equipment and furnaces are developed.

Operator training will have to be provided. Equipment manufacturers, chemical suppliers, or public agencies will need to inaugurate training programs for ethanol plant operations. Section B and Appendix A describe the following six typical plants.

Type	Annual capacity (000 gal)	Proof	Stillage form
Pot still	60	190	wet, 9 percent solids
Small on-farm	160	190	wet, 12.3 percent solids
Large on-farm	360	190	wet, 12.3 percent solids
Small community	1,000	200	wet, 12.3 percent solids
Small community	1,000	200	DDGS, 90 percent solids
Large community	2,000	200	DDGS, 90 percent solids

Section C describes in detail the process used and equipment needed for a one-million gallon per-year plant. In Section C-1, the material balance of a plant is given in terms of materials used per gallon of 200 proof ethanol produced because these ratios are relatively independent of plant size.

Important inputs are 21.6 pounds of grain per gallon of alcohol or 2.5 gallons of alcohol per bushel of grain (corn or sorghum). Five to 12 gallons of water will be required per gallon of alcohol. This will vary with the process and the amount of set back stillage reused in the production process.

The output will be one gallon of alcohol and about 6.1 pounds of dried grains with solubles (dry weight). If stillage is produced, then each gallon of alcohol will be associated with 10 gallons of stillage of 9 percent solids. The exact quantity of stillage and the solids content will vary with operating conditions, particularly with the amount of liquid which might be removed from the stillage and set back into the next cook.

Section C-2 describes the energy balance and cooling water requirements. The basic energy requirements are:

Process	Btu/gal	Cumulative Btu/gal
Cooking	3,700	
Distilling to 190 proof	28,000	31,700
Alcohol dehydrating	20,000	51,700
Stillage drying	32,000	83,700

If the boiler efficiency is 80 percent, then about 100,000 Btu of energy input is required to produce one gallon of ethanol which has an energy value (lower) of 76,152 Btu.

It is quite obvious why the production and use of 190 proof ethanol and stillage are attractive: only about 30 percent of the total process energy is used in the first two steps.

The energy balance also shows the amount of heat which must be removed by cooling water at various points in the process. A total of 46,520 Btu of heat must be removed by cooling water. If well water is available at 55°F and discharged at 110°F, then about 100 gallons of water will be required per gallon of alcohol. A cooling pond could be used instead of a well, but pond water will not be cool enough to cool the fermentation tank in summer. Well or refrigerated water will be needed to keep the fermentors at about 90°F. Because of the cooling water requirement, many beverage distilleries close for one to two months during the summer. Cooling water requirements will be a major factor to consider when selecting a site for a plant.

A sizable operation, of course, might go to water recycling if local conditions (e.g., cost of water relative to the cost of building and maintaining a pond or cooling towers) permit.

Modern ethanol fuel production plants must be designed to achieve maximum production with minimum energy. In order that a variety of types and sizes of production plants could be included in the present analysis, six model ethanol plants were projected. A detailed description of the production process is given for the small community plant producing one million gallon per year of ethanol and distillers dried grains plus solubles.

A. General Design Criteria

Facilities for producing ethanol by fermentation may be grouped according to process type and annual production capacity. These classifications are shown in Table VII-1.

The farmer-built, one-of-a-kind still is expected generally to operate intermittently to produce 160-190 proof alcohol. The wet stillage produced would be utilized in a farmer's own or nearby operation. The plant would not lend itself readily to project type financing and predictable production quantities or quality. At the other extreme is the custom designed, manufactured, and erected large industrial plant producing over 5 million gallon of 200 proof annually and distillers dried by-product. The large industrial plant is outside the size range considered in this study.

The factory-built equipment plant incorporates a standardized design. It is manufactured as an integrated equipment package and is repetitively produced. The sizes and types of these plants range from one of intermittent production of less than 20 gallons per hour to one of continuous production of up to 5 million gallons per year of 200 proof. Plants in this classification are most applicable to farm and community level operations. They are the model basis used for this report.

A number of companies market an ethanol plant of the intermediate type or operate a prototype plant marketing in the near future. However, none of these companies has progressed to the point of having complete operating data on yields or costs.

The characteristics of these plants differ somewhat. Some use mild steel but a few specify such variations as steel-epoxy and fiberglass tanks and stainless steel and steel-copper stills.

With two exceptions, all the plants were designed to use corn as the feedstocks. One plant can use both corn and potatoes and another, both corn and molasses. In practice, probably all could utilize other small grains

Table VII-1. Ethanol plant segments by size and type of manufacturing

Type of manufacturing	Small (< 1 million gallons 160-190 proof ethanol & wet stillage)	Medium (1-5 million gal. 190-200 proof ethanol with wet stillage or DDGS)	Large (> 5 million gal. 200 proof ethanol and DDGS)
Farmer built one of a kind	2-40 GPH intermittant operation	NA	NA
Factory built equipment package repetitively produced and sold as a unit	20-50 GPH intermittant or continuous	150-700 GPH continuous operation	NA
Custom design manufacture and erection	NA	300-700 GPH continuous operation	700-6,000 GPH continuous operation

NA - not applicable
GPH - gallons of ethanol per hour

if their special processing characteristics, e.g. the increased foaming of wheat gluten, are understood when specifying operating procedures. Until operating procedures are finalized and actual operating data are acquired, no conclusion can be drawn as to the relative merits of the various plant designs.

Three features have been identified, however, that affect energy inputs and the efficiency of ethanol fuel production: (a) the design and cost differences necessitated by feedstock variation, (b) types of small boilers available, and (c) plant operating skills required.

1. Variations with Feedstocks

The basic principles involved in ethanol production are the same for all feedstocks; however, the specific feedstocks used affect methods of storage and handling, the hydrolysis of starch or the extraction of sugar, and the processing of the by-products. These differences result in production cost variations.

In using feedstocks other than corn, a number of cost factors need to be considered aside from those for feedstock and the value of the by-product. These latter considerations are addressed elsewhere in this analysis.

Table VII-2 shows the considerations associated with the equipment differences identified with feedstock processing. Corn has been considered the primary feedstock, and a representative number of the potential agricultural products and by-products commonly mentioned as feedstocks are compared to corn. The three sugar crops--sweet sorghum, sugar cane, and sugar beets--have special characteristics that require significantly different equipment.

These sugar crops do not require the hydrolyzing step, for they can be fermented directly once the sugar has been extracted by pressure (in sugar cane milling) or by diffusion (in sugar beet processing). These crops do have a short harvest season, and once harvested they deteriorate rapidly. To avoid a loss of their sugar content, prompt processing is required in warm climates. In Northern areas, sugar beets are usually stored during the winter in a cold or frozen condition and the processing is completed before spring.

Plants processing these sugar crops might be designed to handle multiple crops, i.e., sugars and starches and, thus, operate the year around. (Their cost characteristics are complex and beyond the scope of this study.)

By-product starch and molasses are relatively easy to process, but their availability and supply are limited.

Potatoes can be stored for longer periods than can sugar crops, but the cost of storage is greater. Little cost information regarding cooking and enzyme treatment is available.

Table VII-2. Comparison of process factors of other feedstocks to corn

	Storage length of seam	Feedstock preparation	Sugar extraction	Cooking hydrolysis	Fermentation	Distillation	Dehydration	By-product processing
Corn	grain bins 12 months	grind	none	heat and hydrolyze	with solids	2 columns	Benzene extraction	DDGS or wet stillage
Wheat	grain bins 12 months	grind	none	heat and hydrolyze	same	same	same	DDGS or wet stillage
Milo/sorghum	grain bins 12 months	grind	none	heat and hydrolyze	same	same	same	DDGS or wet stillage
Sweet sorghum	piles 3 months	crush in roller mill	separate sugar & fiber	none	liquid only	larger size	liquid only	low value fiber
Sugar cane	piles 3 months	crush in roller mill	separate sugar & fiber	none	liquid only	larger size	liquid only	low value fiber
Sugar beets	piles 4 months	slice	extensive extraction	none	liquid only	larger size	liquid only	beet pulp dry or wet
Potatoes	controlled atmosphere 12 months	grind	none	heat and hydrolyze	same	somewhat larger size	same	potato pulp dry or wet
Starch	bins 12 months	none	none	heat and hydrolyze	same	same	same	yeast only
Molasses	tanks 12 months	none	none	none	same	same	same	yeast only

Table VII-3 is a subjective comparison of the relative investment costs for processing various ethanol feedstocks. All comparisons are for plants having equal annual capacity and compare costs to those for processing corn.

Not only do the investment costs vary with the characteristics of the feedstocks, but the operating costs vary as well. In Table VII-4 a similar display indicates the magnitude of operating cost by item for these same feedstocks relative to corn. These variable costs, based on a previous study (David, 1978), are given on a per-gallon basis.

2. Biomass Boilers

Ethanol production has a high energy requirement compared to the energy content of ethanol. If ethanol is to make a significant net contribution to the liquid fuels supply, it is imperative that fuels other than fuel oil or natural gas be used for process energy.

Because development of small scale ethanol plants is envisioned for on-farm operation, it has been widely assumed that crop residues (stover) and wood be used as the boiler fuel. Two factors may negate this assumption, however. The first factor is that with the exception of one manufacturer, all present development work utilizes natural gas or oil-fired boilers and no commercially available boilers, in sizes required for these plants, burn solid fuels other than coal or wood. Secondly, plant designers are developing plants with automated features to minimize operator attention; indeed, an automatically controlled boiler is a high-priority requirement. Small boilers burning solid fuels, especially crop residue, are difficult to control unless hand fired, a significant deterrent to automated operation. Additionally, biomass-fueled boilers are still developmental and no commercial units are currently available. Early indications are, however, that biomass boilers will cost two to three times as much as gas-fired boilers.

Farmers themselves could develop such equipment. They could combine tub grinders (capable of grinding large round and conventional rectangular bales) with various stoker and blower devices to automatically feed the fire box of a variety of standard boilers.

In general, this study's state-of-the-art review of boiler construction indicates that much research, testing, and evaluation needs to be done on boiler characteristics to adequately assess their effect on ethanol production costs.

3. Operator Training

The efficient operation of a still requires careful attention to many details with which most farmers are not familiar. Sanitation requirements are extremely high (similar to those of a Grade A dairy operation) to prevent the growth of undesirable organisms during fermentation that could, at best reduce yields and, at worst, result in toxic, unusable by-products.

Table VII-3. Comparison cost of investment of other feedstocks with corn for same ethanol capacity

	Feedstock storage	Feedstock preparation	Hydrolysis or sugar extraction	Distillation	Dehydration	By-product drying	Total Investment
Corn	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Wheat	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Milo/sorghum	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sweet sorghum 1/	0.3	3.0	0.1	3.0	3.0	0.1	2.5
Sugar cane 1/	0.3	3.0	0.1	3.0	3.0	0.1	2.5
Sugar beets 1/	0.3	4.0	2.0	3.0	3.0	1.5	3.0
Potatoes	1.5	1.2	1.0	1.2	1.0	1.0	1.2
Starch	0.5	0.1	0.8	1.0	1.0	0.1	0.8
Molasses	0.5	0.1	0.1	1.0	1.0	0.1	0.7

1/ Assumes that plant with some total annual capacity will have to have three times capacity per month because of approximately four month season.

Table VII-4. Comparison of operating costs[1/] per gallon of processing other feedstocks with corn for plants of same ethanol capacity

	Total Costs					Indirect Costs				Direct & Indirect
	Labor	Fuel	Electricity	Other	Total	R&M	Ins. & Tax	G&A	Total	Total
Corn	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Wheat	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Milo/sorghum	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Sweet sorghum	1.2	0.8	1.0	0.8	1.0	1.3	2.0	1.0	1.4	1.2
Sugar cane	1.2	0.8	1.1	0.8	0.9	1.3	2.0	1.0	1.5	1.3
Sugar beets	1.3	1.2	1.2	0.8	1.2	1.5	2.5	1.0	1.6	1.5
Potatoes	1.1	1.3	1.0	1.0	1.2	1.2	1.0	1.0	1.1	1.1
Starch	0.7	1.0	0.8	0.9	0.8	0.8	0.8	0.9	0.8	0.8
Molasses	0.6	0.7	0.7	0.8	0.7	0.6	0.7	0.9	0.7	0.7

1/ Costs of operation do not include feedstock cost or by-product credit.

Care must be taken to monitor pH and temperature levels and to control the conversion of starch to sugar, the conversion of sugar to alcohol, etc. And, in addition, safety requirements to prevent fire and explosion are greater than for most farm operations. Alcohol vapors are as hazardous as those of gasoline.

To assure efficiency and safety, then, operator preparation should include one of the following:

- training by the equipment supplier at the factory or on the job,
- training by the supplier of such materials as enzymes and yeast, or
- training by public agencies such as vocational schools and agricultural extension services.

The training of farmers or others probably will need to be done in each state where a significant number of plants are located. If public financing is used, then some of the first installations might be given additional assistance (grants) in return for their being available as training sites.

If training is to be done by the public sector, an intensive program should be inaugurated soon to train teachers. Training sites will be limited since only one or two relatively complete stills are known to be located in colleges or universities.

The length of the training course should be of the order of at least one week. If a pot still is used, it will require most of this time to cook, ferment and distill one batch.

In some areas and for installations which use larger boilers and/or steam pressures above 15 pounds per square inch, it may be necessary to employ state licensed engineers.

B. Model Small Scale Ethanol Plants

This study developed six model small scale ethanol plants which encompass the ranges of types and sizes of plants currently being marketed. These model plants were designed to be characteristic of plants projected for on-farm and rural community operation in the near term. These six plants vary by ethanol processing, capacity, product proof, style of operation, and the form of the by-product stillage.

Table VII-5 outlines the following six distinctive small scale plants.

- Pot still, intermittent production of alcohol and wet stillage
- Small on-farm, intermittent production of alcohol and wet stillage
- Large on-farm, continuous production of alcohol; wet stillage

- Small community, continuous production of alcohol; wet stillage
- Small community, continuous production of alcohol; DDGS
- Large community, continuous production of alcohol; DDGS

In addition, a model central dehydration plant was designed. This plant would operate as an addition to the community size plants and have an excess dehydrating capacity. For the latter portion of the operation, lower proof alcohol would be collected from nearby small stills for processing to 200 proof.

A more detailed description of each of these plants is given in Appendix A.

A detailed description of the small community model plant process is given under "C" below. This plant produces one million gallon of ethanol per year, produces distillers dried grains, and vents the carbon dioxide. Variations from this process occur for the other five model plants (the characteristics of these plants are shown in Table VII-5). The pot still differs in that both the hydrolysis and fermentation operations are performed in one vessel, i.e., there is no separate cooker and fermentor. The entire contents in this one vessel are heated to obtain the alcohol by distillation, leaving the distillers by-product. The alcohol vapors are condensed into a receiving vessel.

The processes of the remaining plants are similar in all respects to that detailed in "C" up to the end of the distillation process. Only the three largest plants have dehydration capabilities. The smaller three produce 190 proof ethanol. In the small and large on-farm units and the small community plants, the stillage is sold or disposed of in the wet state, at 12.3 percent solids. Only the two largest plants dry their by-product.

The energy balance for the described plant is shown in detail. The four smaller plants will show smaller energy input per gallon since the stillage is not dried. Additionally, the three larger plants have energy requirements for the alcohol dehydration step. However, as the plant size and energy use increase, various heat exchanges become more feasible, steps that decrease energy use.

The materials balance will be similar for those plants that utilize the same percentage set back. The variations occur in the point at which water leaves the plant--in the stillage or via the dryers.

C. Process Description, One Million Gallon Per Year Plant

The process described here assumes a grain feedstock such as corn or sorghum (milo). The process shows an end product of 200 proof, nominal, alcohol and a dry-product of "distillers dried grains with solubles." Variations which might occur with other feedstocks or end products will be discussed at appropriate points.

Table VII-5. Model small scale ethanol plants characteristics

Model plant designation	Size	Distillation			Operation schedule		Annual production	By-product type	Plant construction type
		Type	Rate	Proof					
			(GPH)		(Hrs/day)	(Days/yr)	(000 gal/yr)		
Pot still	Small	Intermittent	20	160-190	8	100	16	Wet stillage	Pot still package
Small on-farm	Small	Intermittent	25	190	8	300	60	Wet stillage	Package plant
Large on-farm	Medium	Continuous	50	190	24	300	360	Wet stillage	Package plant
Small community, wet	Large	Continuous	150	200	24	300	1,000	Wet stillage	Custom built
Small community, DDGS	Large	Continuous	150	200	24	300	1,000	DDGS	Custom built
Large community, DDGS	Large	Continuous	300	200	24	300	2,000	DDGS	Custom built

As shown in Figure VII-1, grain is received by trucks which are weighed on truck scale A. Receiving by rail would require an additional scale--either a rail track scale or more generally a small automatic post weighing hopper scale. The same truck scale A will be used for weighing out products shipped.

Trucks are unloaded in a truck dump hopper, "B" which is covered with a coarse grate to prevent large foreign objects from entering the conveyors. No truck dumping device is shown because most semi-trailers for grain hauling are now equipped with hopper bottoms for emptying; most small farm trucks are equipped with hydraulic hoists. Grain is received at an average daily rate of less than 1,500 bushels. This requires about one and one-half semi-trailer loads per day. A receiving rate of 1,000 bushels per hour was assumed.

Conveyor "C", moves grain from the dump hopper to "D", a simple scalping screen (about one-inch screen openings) to remove large pieces of foreign material. Grain is conveyed through a screw conveyor, "E", and bucket elevator "F" to storage bins "G". Two bins of 10,000 bushels each are provided. Their total capacity can provide a 14-day supply. Two bins are used to allow some flexibility in segregating by quality, e.g., high moisture grain.

A small hammermill "J" is sufficient to grind the grain on an almost continuous operating basis as ground grain is accumulated in scale hopper "L". The hammermill will be provided with a magnet, "I" to remove iron objects. About a 3/16 inch screen would be used with normal moisture corn or sorghum.

Ground grains are conveyed by "M" to the cooker "N" (Figure VII-2) which operates on about a four-hour cycle with two cooks required to fill one fermentor tank.

Feedstocks other than grain will require appropriate receiving, storage and processing equipment. Potatoes would require different types of conveyors to avoid excessive damage and a different type of storage structure. A chopper with screen would replace the hammermill.

Sugar base stocks such as sugar cane, sweet sorghum, and sugar beets will require chopping, pressing, and washing to remove plant juices. Most of the by-product would be removed at the processing section and would probably be disposed of as a wet product; dried beet pulp, however, is a well-established commercial feed ingredient.

The cooker tank "N" is specified as mild steel, but other materials such as fiber glass or stainless steel would reduce maintenance costs. Its working capacity is about 75 percent of the total tank capacity. The tank is equipped with cooling coils "P" and steam sparging "O".

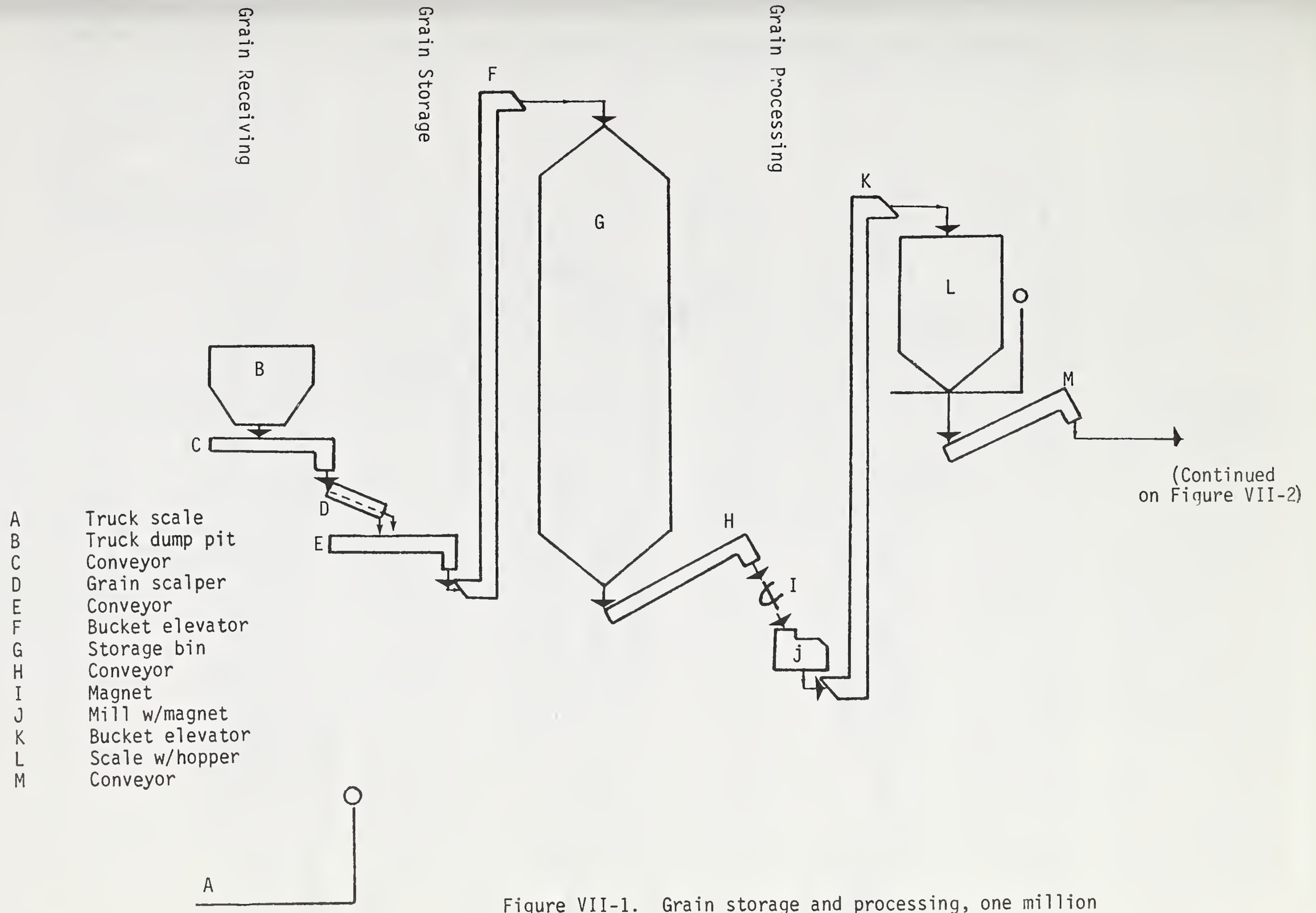
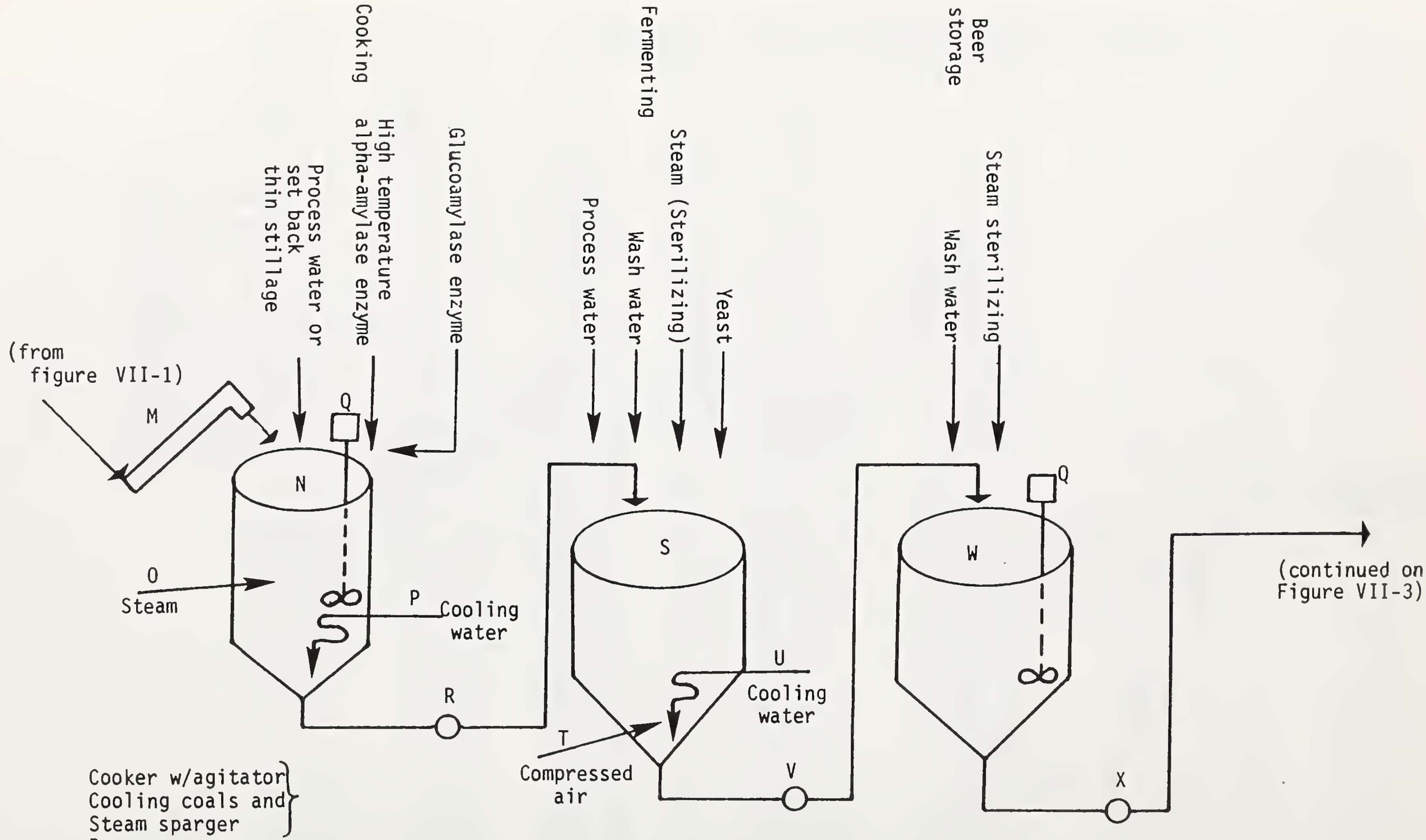


Figure VII-1. Grain storage and processing, one million gallon plant



Cooker w/agitator
Cooling coals and
Steam sparger
Pump
Fermentation tanks w/cooling coils and air sparging, steam and water cleaning
Pump
Beer well w/agitator steam & water cleaning
Pump

Figure VII-2. Cooking and fermenting, one million gallon plant

To prevent lumps in the mixture, cooker water is first provided and, then, the grain is added. Process water may be fresh water, but the flow shown uses thin stillage. Although experts do not agree on just what fraction of the process water can be reused, they do agree that cooking and fermentation can use by-product still water (called set back or back set). Maximum reuse of set back will reduce drying costs for the by-product and distillers dried grains and will reduce the amount of steam required for cooking the mash.

During filling and cooking, the agitator mixer, "Q", is operating continuously to further prevent lumping and to mix the enzymes thoroughly. Adding the grain will lower water temperature sufficiently to allow a part or all of the liquifying (alpha-amylase) enzyme to be added. The temperature is then raised to 210° by direct steam injection and held for one hour for cooking.

The temperature is then reduced to 130°F before the glucoamylase enzyme (somtimes referred to as "saccharifying enzyme") is added to complete the conversion of starch to glucose (sugar). After cooling to about 110° with cooling water through cooling coils or a heat exchanger, the mash is transferred (two batches) to the fermenting tank.

Potato feedstock will require the same cooking and enzyme treatment as grain. Less water will be needed because of the high intitial moisture content. Sugar crop juice will not require cooking; the juice will be ready for fermentation.

Fermenting tanks, "S", are again specified as mild steel and must be equipped with cooling coils. They must be covered to prevent the entry of oxygen in the air because the fermentation is an anerobic process. A vent must be provided to release the carbon dioxide produced. To provide for a three-day fermentation cycle employing three tanks per day (and one under maintenance), ten tanks are specified. The tank working capacity is about 75 percent of the total capacity.

After the 110° mash is added, additional fresh, cool process water is added to reduce the temperature to about 90°, an optimal temperature for the yeast. Yeast is then added to the cooked mash and allowed to ferment for about three days. Cooling water, "U", must be used to remove heat produced by the fermentation. At the end of the fermentation, the beer should contain about nine percent alcohol.

The fermenter is emptied into a beer well by a high volume pump to allow it to be refilled as soon as possible. During emptying, compressed air, "T", is introduced into the bottom of the tank to keep solids in suspension. As the surface of the beer moves down, the walls are sprayed with high pressure water, and after emptying, the tank is sterilized with steam.

Sanitation of the fermenting equipment prior to and during the process is of greatest importance to prevent the introduction and growth of undesired microorganisms. The beer well, "W", is a simple storage tank with an agitator, "Q", where beer is held while being slowly pumped to the distillation section. About eight hours will be required to empty one fill from the beer well.

Beer distillation begins as the beer is pumped from the beer well to the stripper column (Figure VII-3) through two heat exchangers. The first heat exchanger, "Y", uses some alcohol vapor heat to preheat the beer which then moves to a second heat exchanger "Z" where the beer is heated to a temperature of about 185^{o} by heat from the stillage out of the stripper column.

Beer is introduced near the top of stripper column "AA" at about the 25th plate. The stripper column is a vertical pipe with horizontal perforated plates spaced at about six inch intervals and held in place by spacers. The designs of distillation columns vary and must ultimately be tested in actual operation. Beer trickles down through the plates where it is heated by the alcohol and water vapor that are moving upward. At the bottom of the tower, a pool of beer is kept at a temperature of about 225^{o}. At this temperature, essentially all of the alcohol will have been removed and the pressure will be slightly above atmosphere.

The temperature of the liquid at the bottom of the column could be maintained by direct steam injection, but a heat exchanger (calandria), "EE", is shown. (Direct sparging of steam into the column adds water which later must be removed.)

A high capacity pump, "BB", circulates liquid through the calandria. Flow divider "DD" diverts some liquid back to the column and some back for re-circulation through the calandria. Another flow divider, "CC", allows stillage to leave the column at the rate required to maintain a constant liquid level at the bottom of the column. A mixture of alcohol and water vapor leaves the top of the column at about 100-proof.

Distillation of beer from potatoes and sugar crops will not differ from that from grains.

The 100 proof vapors at a temperature of about 201^{o} are introduced at the bottom of the rectifying column, "FF", which contains about 30 perforated plates. As vapor rises in the column, water condenses and moves downward and alcohol vapor moves upward. At the top of the column, the vapor is at about 190 proof equivalent. Water with some alcohol is pumped back from the bottom of the rectifying column to the top of the stripping column.

Two-thirds of the condensed 190 proof alcohol from the top of the column is refluxed back into the column and the other one-third, 190 proof alcohol, goes to storage or to dehydration.

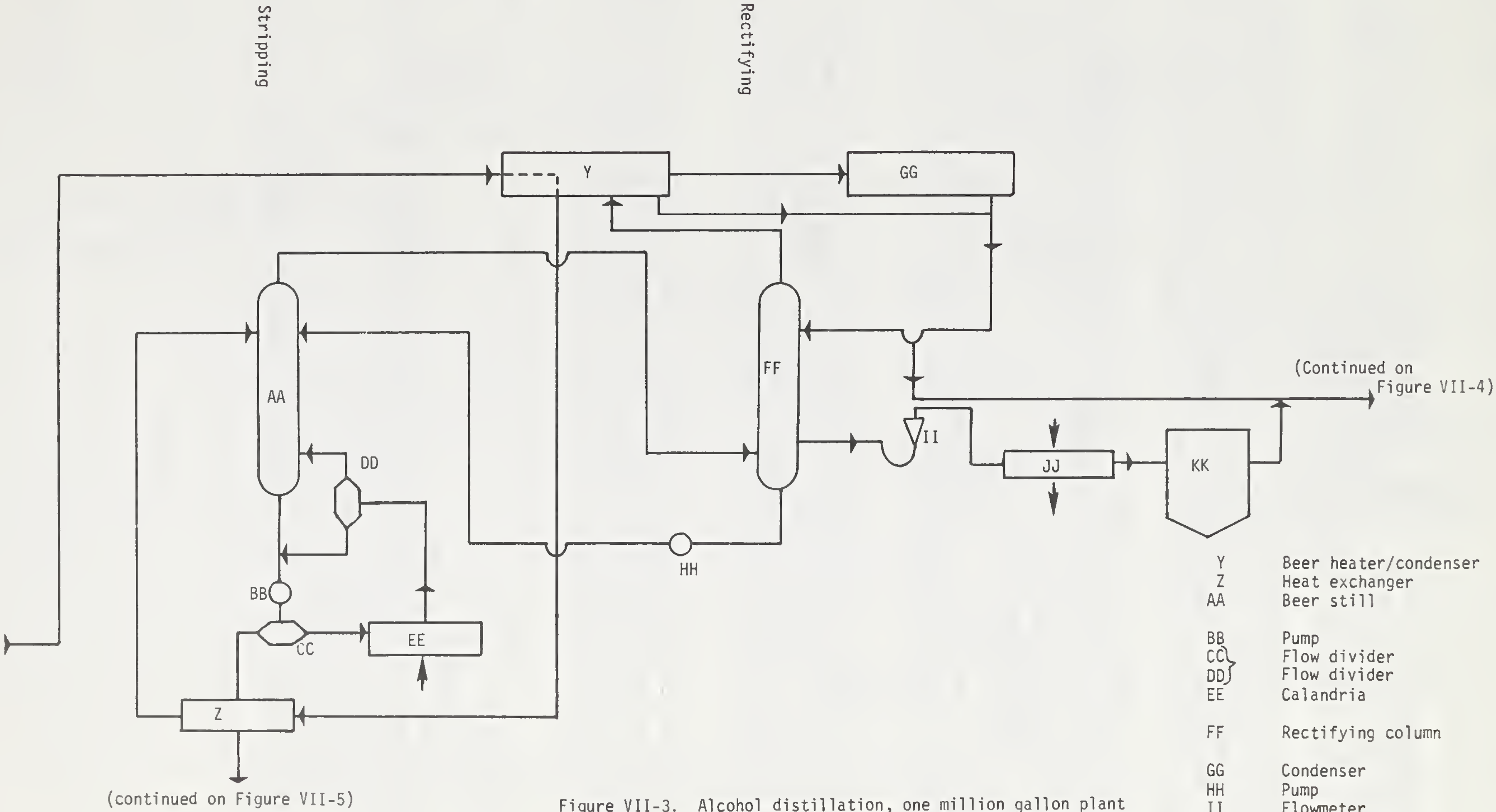


Figure VII-3. Alcohol distillation, one million gallon plant

Y	Beer heater/condenser
Z	Heat exchanger
AA	Beer still
BB	Pump
CC }	Flow divider
DD }	Flow divider
EE	Calandria
FF	Rectifying column
GG	Condenser
HH	Pump
II	Flowmeter
JJ }	Heat exchanger w/
KK }	Decanter

Alcohol vapors are condensed in heat exchangers "Y" and "GG". Final liquid alcohol of about 190 proof is produced.

At an intermediate point within the rectifying column, fusel oil will condense and must be removed. For beverage alcohol, the fusel oil would be disposed of, but here it can be recombined with the condensed alcohol since its fuel properties are similar to those for alcohol.

At this point, a fuel alcohol which would be adequate for many purposes has been produced. However, it is not satisfactory for gasohol since with the four percent water, it would not mix with gasoline. The next step (Figure VII-4) in the process, dehydration, is difficult and requires significant energy and/or expense to raise the proof from about 190 to about 200.

One of the older dehydration methods uses calcium oxide to remove the water. Vacuum distillation could be used. The most common method now used involves mixing benzene with the 190 proof alcohol and repeating the distillation process in two or more towers. This process introduces alcohol of 190 proof into a dehydrating column, "LL", where it is mixed with benzene. The resulting mixture of ethanol, benzene and water has different vaporization characteristics than that of ethanol and water, and a very high proof alcohol can be removed from the bottom of the column. Heat for vaporization is provided through a heat exchanger, "NN".

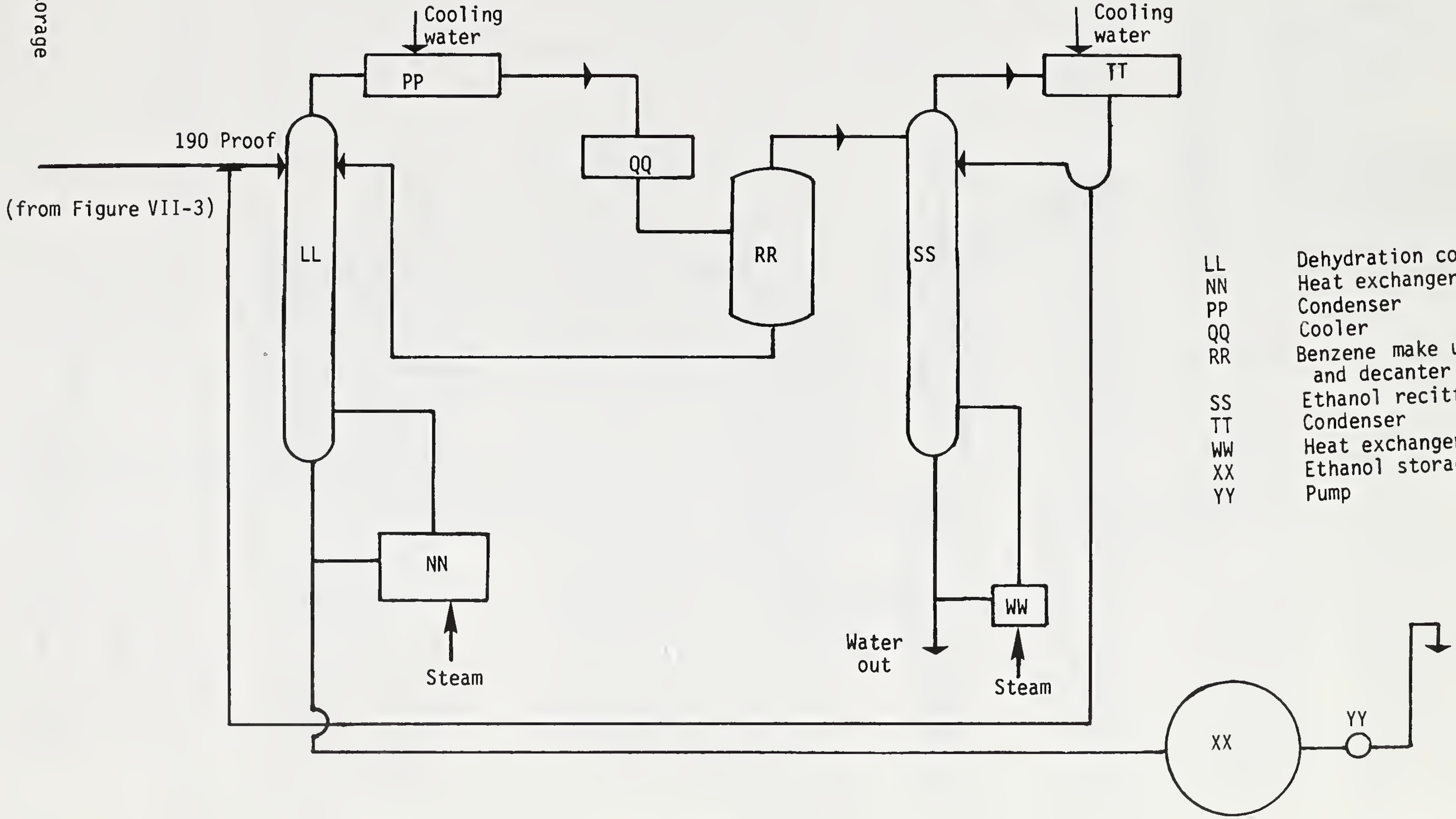
A mixture of ethanol, water, and benzene vapors is removed from the top of the dehydrating column, condensed in the heat exchanger, "PP", and the resulting liquid is cooled in the cooler, "QQ". The cooled liquid is separated in the decanter "RR" where a benzene-rich stream is taken back to the dehydrating column and a water-rich stream is taken to the ethanol rectifier, "SS".

With the ratio of ethanol, water, and benzene taken to the ethanol column, "SS", almost pure water will be condensed and removed from the bottom of the column and a vapor mixture removed from the top of the column. After the liquid mixture is considered, it is recirculated to the dehydrating column.

The final, nominal 200 proof alcohol is stored in storage "XX" for delivery through pumps "YY".

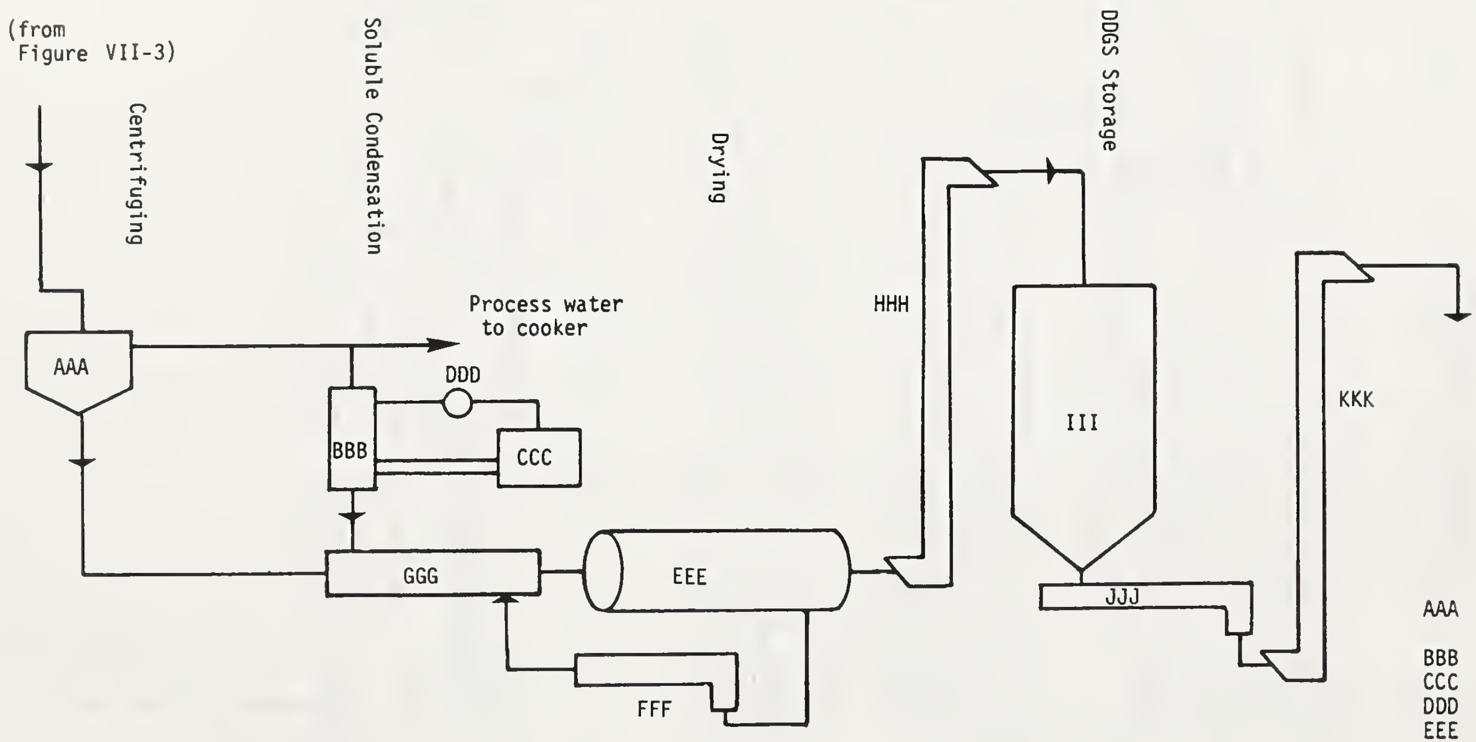
Stillage removed from the stripping column, "AA", through the heat exchanger "Z" is separated by a centrifuge, "AAA", to give high and low solids fractions. This process could be accomplished less efficiently by a sieve or more efficiently by a press (Figure VII-5).

The high solids fraction, about 30 percent solids, could be utilized as wet distillers grains or dried as shown to produce a more stable, higher value product.



LL	Dehydration column
NN	Heat exchanger
PP	Condenser
QQ	Cooler
RR	Benzene make up and decanter
SS	Ethanol recitfyer
TT	Condenser
WW	Heat exchanger
XX	Ethanol storage
YY	Pump

Figure VII-4. Alcohol dehydration, one million gallon plant



AAA	Stillage centrifuge
BBB	Recompression evaporator
CCC	Vapor separator
DDD	Compressor and turbine
EEE	Rotary dryer
FFF	Conveyor
GGG	Mixer
HHH	Bucket elevator
III	DDGS storage
JJJ	Conveyor
KKK	Bucket elevator

Figure VII-5. Grain drying, one million gallon plant

The low solids faction (about three percent solids) of largely soluble protein and minerals is used for two purposes. A part of the liquid can be taken back to the cooker for reuse to reduce the energy required for cooking and for by-product drying. The exact quantities desirable for maximum efficiency are not well determined since beverage distillers do not follow the practice, except in the production of "sour mash" products, where the percent set back is regulated.

Liquid not used for set back can be most efficiently dried in multiple-effect or, as shown, vapor-recompression evaporators. The efficiency of the vapor recompression evaporators, "BBB" and "CCC" is at least twice that of ordinary evaporators, but a plant of the size described is near the lower end of the range where they would be feasible.

The vapor recompression compressor "DDD" would be powered by a relatively cheap and simple steam turbine, and the exhaust from this turbine would be used for the distillation columns. In this manner, conisderable energy efficiency is achieved compared to powering the compressor with an electric motor.

The condensed solubles, about 50 percent moisture, are mixed with the wet grains and drying is completed in a drum dryer, "EEE". A portion of the dried products must be recirculated, "FFF", to prevent wet products from sticking in the drum.

Dried grains are stored in "III" for delivery and about 10 days of storage capacity is provided. Since the by-product from potato feedstock will not differ appreciably from that from grains, the same equipment would be used. The by-product, primarily yeast, from the sugar feedstock will be very low in solids. No liquid would be needed for set back. Centrifuging, which could concentrate the yeast would probably be impractical because of the thin liquid which would remain for disposal. Vapor recompression condensing would probably be used ahead of drum or spray drying. Brewers yeast is a valuable feed ingredient which sells at about three to four times the price of distillers dried grains. Condensed yeast could be marketed, but the high commercial value of dried yeast should easily compensate for the higher cost of the dried product.

1. Material Balance

An accurate materials balance assessment is important to an analysis of ethanol production. The materials balance shows where various materials enter and leave the system and is used later in computing the production process energy balance. The present material balance assessment, Figure VII-6, is based upon that for one gallon of 200 proof alcohol and would not vary too much with size of installation. To calculate total tank and equipment capacity does require additional calculation, primarily multiplying by the alcohol production rate in appropriate time units.

Grain enters the storage processing section where a loss of about 0.5 percent occurs due to cleaning.

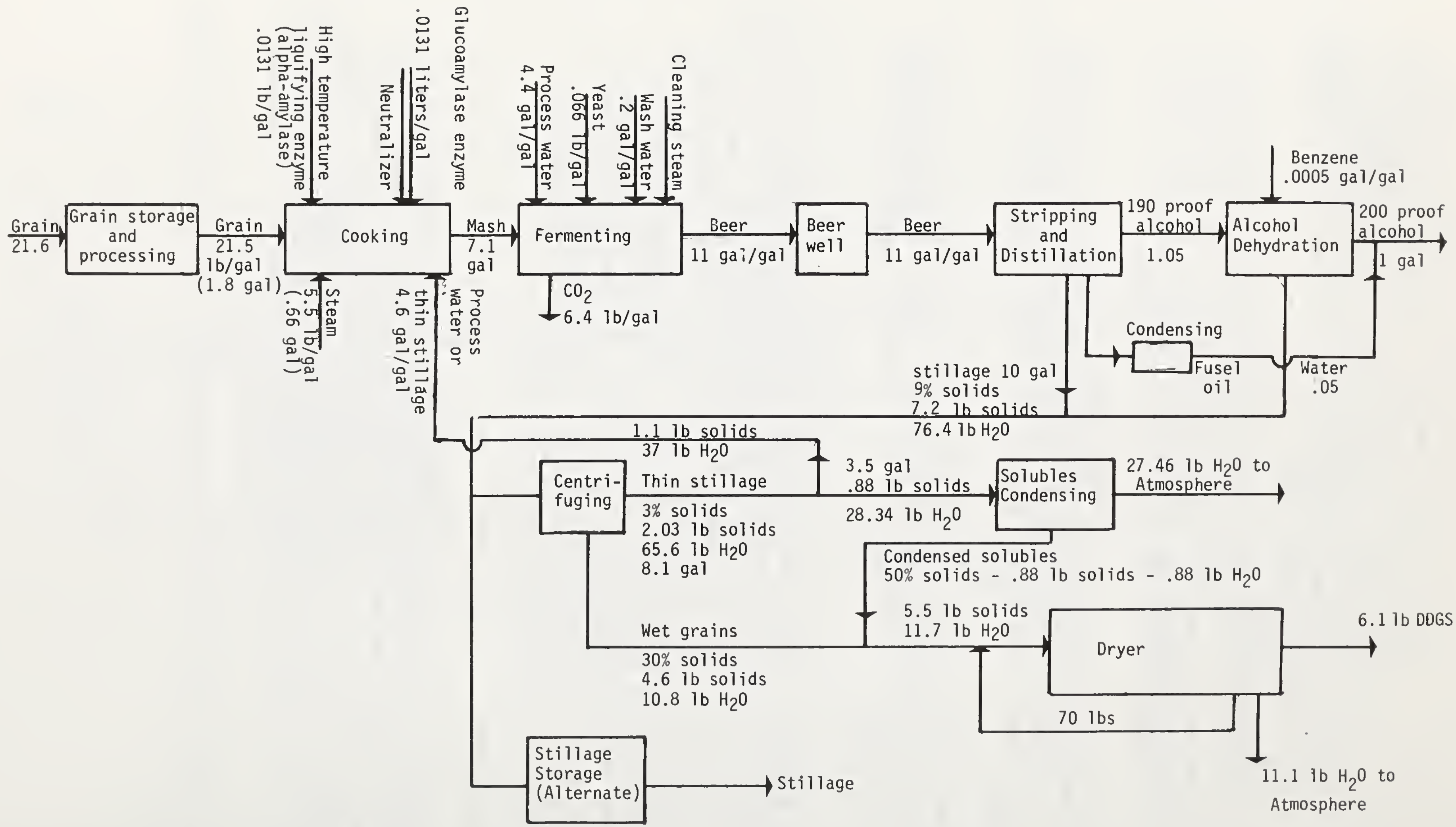


Figure VII-6. Material balance of distillery

Materials entering the cooker consist of ground grain, process water (shown here as set-back thin stillage), steam, neutralizers, and enzymes. After cooking and enzyme treatment, the mash is pumped to the fermentor where additional process water and yeast are added. Outgoing material is primarily beer containing about nine percent alcohol and carbon dioxide. In a very large plant, the carbon dioxide might be recovered as a salable by-product.

Beer to the stripping and distillation section yields three products--stillage, 190 proof alcohol, and fusel oil. The stillage becomes an animal feed by-product, and the fusel oil can be combined with fuel grade alcohol. The 190 proof alcohol could be used as a fuel for many purposes or dehydrated to 200 proof for use in gasohol.

Stillage at about nine percent solids could be sold for animal feed or its value could be increased by drying. After centrifuging, the high and low solids streams are treated differently. Some of the low solids stream can be reused in the process, and the rest, after condensing to about 50 percent solids, could be sold as condensed solubles or dried on the grains.

As shown, 21.6 pounds of grain (13 percent moisture) produces the final products of one gallon of alcohol, 6.4 pounds of carbon dioxide, and 6.1 pounds of dried grains.

2. Energy Balance

The energy balance, Figure VII-7, shows where electrical or heat energy enters and leaves the processing system and does not include feedstock, product, and by-product. This analysis is required to determine electrical, steam, and cooling water requirements. The flow shows the energy consumption based upon one gallon of 200 proof alcohol and can be applied to other similar installations by applying an appropriate production rate factor. The main use of the analysis will be to determine steam and cooling water requirements.

In the cooking process about 3,680 Btu per gallon are required to raise the temperature of the grain from about 60^{o} and the set back water from about 150^{o} to a final temperature of 210^{o}. After the cooking process, about 6,130 Btu must be removed to reduce the mash temperature to about 105^{o}, and the amount of cooling water needed depends upon that water's original temperature. Much less water would be required if 60^{o} well water is available than if 80^{o} cooling pond water is used.

When the mash enters the fermentor, it will be cooled to about 90^{o} by the addition of 60^{o} process, well water. Additional heat of fermentation, about 2,390 Btu per gallon, must be removed by cooling water. This cooling step is a significant system constraint since cooling water with a temperature of below 90^{o} must be available, a temperature difficult to obtain without an artificial, mechanical, or refrigeration unit. Many beverage distilleries simply close down during the hottest summer weather for one to two months. Cooling ponds or spray cooling towers may be adequate in most areas, but they will require very site specific designs. Failure to keep the fermenting tanks at about 90^{o} will result in slower fermentation and/or lower yields.

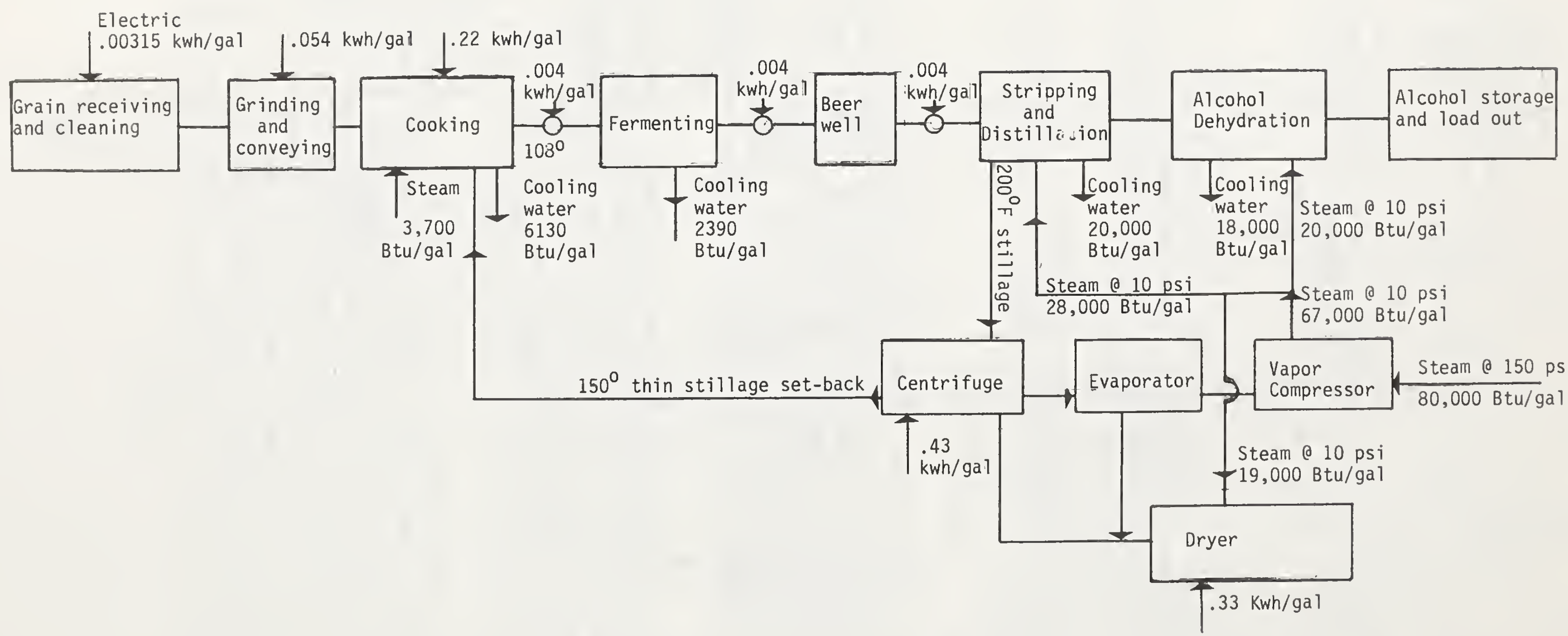


Figure VII-7. Energy balance (including process and cooling water)

Stripping and distillation are energy intensive. Considerable efficiencies could probably be achieved by a substantial investment in research and development. Potential efficiencies are possible through improved column design, through using vapor recompression techniques, and by producing ethanol of lower proof.

Alcohol dehydration to raise the product from 190 to 200 proof requires almost as much energy as the original distillation of the 190 proof. An incentive to utilize lower proof fuels or to develop emulsifiers for gasohol products that would facilitate lower proof use.

By-products dehydration also requires major energy inputs. Smaller installations will achieve drastic efficiency improvement by disposing of stillage. Larger installations could achieve significant savings by installing co-generation systems within which electricity would be generated and sold and the waste heat used for drying.

Site specific installations might find relatively low temperature heat available which could be used for by-product drying and distillation. Unfortunately, most existing electrical power generating plants have been designed to dispose of waste heat at too low a temperature to be of value for alcohol production, but designing new plants for cogeneration will provide the opportunity for significant energy improvements.

The energy requirement of about 84,000 Btu per gallon represents about 100 percent of the energy value of the alcohol produced. For this reason, extensive effort must be devoted to using low grade and low price fuels such as coal, biomass, methane, etc. rather than petroleum fuels.

SUMMARY

VIII. COSTS OF ETHANOL PRODUCTION

Chapter VIII estimates the costs of small scale ethanol production by considering the feedstock and by-product prices and the operating, maintenance, and capital costs of the types of plants discussed in Chapter VII. These cost estimates are based on the best current information; however, there is no operating history of small scale ethanol plants from which actual operating characteristics and costs can be derived. Only as operating experience and records become available can these costs be refined. The base cost estimtes for the four major groups of cost elements are as indicated below.

Feedstock

In this analysis, corn is used as the basis for estimating feedstock cost due to the current interest in that grain. The long-term corn price received by farmers was used for the on-farm plants on the assumption that this price of $2.50 per bushel reflects farm level prices. For the community plants, the long-term major market average corn price was used--$2.75 per bushel.

Although to date small plant operators report lower actual ethanol yields, the ethanol yield rates of 2.4 gallon per bushel for the pot still and 2.5 gallons per bushel for the other sizes are believed to be reasonably achievable.

By-Product Credits

The feeding value of wet stillage appears to vary by class of livestock and ranges from about $110 to $200 per ton of DDGS equivalent. For cost estimating purposes, the single values selected as representative of each model's stillage and market situation were:

Type of process	Stillage Yield	Stillage Dry matter (%)	Price 10% moisture $/ton
Pot still	21.4 gal/bu	9	67
Small on-farm	15.7 gal/bu	12.3	153
Large on-farm and small community	15.7 gal/bu	12.3	135
Community, DDGS	17.8 lbs/bu	90	130

Operating and Maintenance Costs

Operating and maintenance costs include labor, energy, electricity, supplies (enzymes, yeasts, etc.) repairs and maintenance, taxes, insurance, and general and administrative expense. The basis for estimating and these costs are given in Appendix A.

Capital Costs

Estimated annual ethanol capital costs must reflect investment costs that are capitalized (amortized) and recovered over the life of the plant. Estimated investment costs for the various plants are tabulated in Appendix A.

In order to estimate annualized capital cost, a discounted cash flow model that reflects key financial parameters (including the depreciation method, capital structure, cost of debt, cost of equity, investment tax credits, federal and state income taxes, and inflation rates) was used to provide a capital cost recovery factor. The equivalent annual capital cost is calculated by multiplication of the appropriate factor (Table VII-2) times the total investment, including working capital.

Cost of Production

By utilizing the preceeding cost elements, the analysis estimated the costs of producing ethanol as:

Type of plant	Ethanol proof	Cost of production $/gal
Pot still	190	1.63
Small on-farm	190	1.34
Large on-farm	190	1.13
Small community, wet	200	1.21
Small community, DDGS	200	1.38
Large community, DDGS	200	1.29

Variations reflect the size of plants, the achieved alcohol proof, and the type of stillage produced.

These base costs reflect the current best estimates of plant operating characteristics and costs. In order to provide additional perspective to the cost estimates and to provide information to users to estimate costs for specific situation, the analyses included an extensive sensitivity analysis for the major cost elements. The effect of different operating characteristics and cost levels are shown graphically (Appendix B).

Of the eleven variables analyzed, feedstock prices had the greatest impact. Relatively large effects were found also for production levels, ethanol yields, and by-product prices.

To place the estimated costs of ethanol production in perspective, the fuel value of ethanol in four applications--gasohol, straight ethanol, carbureting into diesel engines, and grain drying--was compared with the volumetric value of the fuel for which the ethanol could potentially substitute. For these four types of applications, the costs of production in small scale ethanol plants exceeded their fuel value in all cases. The comparisons of the estimated ethanol production costs and fuel values under differing situations are shown in Table VIII-1 for on-farm (net of taxes) gasoline price of $0.97 per gallon and a diesel fuel price of $0.90 per gallon.

Table VIII-1. Comparison of estimated ethanol production costs and fuel values under differing situations

Pot still	Cost of production	Fuel value 1/				Cost less fuel value			
		Gasohol 2/	Straight	Carbureting in diesel engines	Crop drying	Gasohol	Straight	Carbureting in diesel engines	Crop drying
	($/gal)								
Pot still									
200 proof	1.80 3/	.64	.74	4/	.51	1.16	1.06	4/	1.29
190 proof	1.63	5/	.64	4/	6/	5/	.99	4/	6/
Small on-farm									
200 proof	1.51 3/	.64	.74	4/	.51	.87	.77	4/	1.00
190 proof	1.34	5/	.64	4/	6/	5/	.70	4/	6/
160 proof	1.00	5/	.49	.40	6/	5/	.51	.60	6/
100 proof	.62	5/	--	.25	6/	5/	--	.37	6/
Large on-farm									
200 proof	1.30 3/	.64	.74	4/	.51	.66	.56	4/	.79
190 proof	1.13	5/	.64	4/	6/	5/	.49	4/	6/
Small community, wet									
200 proof	1.21	.64	.74	4/	.51	.57	.47	4/	.70
Small community, DDGS									
200 proof	1.38	.64	.74	4/	.51	.74	.64	4/	.87
Large community, DDGS									
200 proof	1.29	.64	.74	4/	.51	.65	.54	4/	.78

1/ Compared to gasoline at $0.97 per gallon (net of taxes) diesel fuel at $0.90 per gallon (net of taxes) and LPG at $.55 per gallon delivered.

2/ When applicable this value could be increased by $.10 per gallon for the octane credit.

3/ Assumes upgrading to 200 proof at a central dehydration still at a cost of $.17 per gallon.

4/ Technically feasible, but lower proof use likely.

5/ Not applicable, 200 proof ethanol required.

6/ 200 proof ethanol most suitable for this application.

VIII. COSTS OF ETHANOL PRODUCTION

This chapter presents the estimated costs of small scale ethanol production. It brings together feedstock and by-product prices and operating, maintenance and capital costs into an estimated production cost for the various types of ethanol plants discussed above in Chapter VII. It should be recognized that while these cost estimates are based on the best information now available, there is not an operating history of small scale ethanol plants from which actual operating characteristics and costs can be derived. As operating experience and records become available, these cost estimates can be refined.

The chapter first establishes a set of base conditions which reflect the current best estimates of plant operating characteristics and costs. Then extensive sensitivity analyses are presented to show the effect of such different operating characteristics and cost levels. This type of analysis not only dramatically shows the important cost elements, but it also provides a basis for users of this report to adjust the base case results to their particular situation. The results of the sensitivity analysis are depicted graphically in Appendix B.

In making the base cost estimates, inputs values were determined by estimating the potential worth to investors of those inputs. For example, for the small on-farm pot still, it was assumed that land and certain grain handling and grinding equipment were already owned by the farmer. Corn was valued at the long-term price received by farmers on the basis that it could alternatively be sold rather than processed into ethanol. Labor was valued as if it were hired. However, a specific investor (particularly at the farm level) may have unique circumstance regarding the availability of land or grain handling equipment or may perceive the value of his corn or labor differently. In such instances, the sensitivity analysis can be used to estimate these potential input values for specific situations.

The last part of this chapter examines these estimated costs in relation to ethanol fuel values for selected applications.

A. Cost Elements

The cost elements can be broadly grouped into four major groups--feedstock costs, by-product credits, operating costs and capital costs. Within each of these are subelements involving input-output rates and prices. This section presents the values used to make the base cost estimates.

Because of the paucity of information regarding plants using non-grain feedstocks, the cost estimates presented herein are based on grain. Although all grains can be used as a feedstock, corn currently commands the most interest and is used as the basis of estimating feedstock cost.

1. Feedstock

Corn prices vary by location and reflect local supply-demand conditions, transportation facilities, and markets. For purposes of these cost estimates, the long-term corn price received by farmers was used for the on-farm plants on the assumption that this price reflects farm-level prices. For the large community plants, a higher price reflecting the long-term average corn price at major markets was used to, in turn, reflect the additional transportation and competitive pressures which a larger plant would face. Specifically a farm price of $2.50 per bushel (1979 dollars) and an off-farm price of $2.75 per bushel (1979 dollars) were used. It is noted that the average farm price of grain sorghum is about $2.25 per bushel (1979 dollars) and the major market price is $2.60 to $2.90 per bushel (1979 dollars) for Kansas City and Fort Worth, respectively.

In addition to differing price levels, various theoretical ethanol yield rates were used. The base case estimates were based on the following yields:

Type	Proof	Yield (gal/bu)
Pot still	190	2.4
Small on-farm	190	2.5
Large on-farm	190	2.5
Small community, wet	200	2.5
Small community, DDGS	200	2.5
Large community, DDGS	200	2.5

To date several operators have reported ethanol yields and these have been lower than those shown above. However, under proper operation, particularly with regard to cooking, these yields are believed to be reasonably achievable. The pot still yield was reduced below the other on-farm units to reflect less than optimal operating conditions for a very small unit of this type.

2. By-product Credits

As discussed in Chapter VI, the feeding value of wet stillage appears to vary by class of livestock and ranges from about $110 to $200 per ton of DDGS equivalent. For cost estimating purposes, a single value was selected as representative of each model plant's stillage and marketing situations.

The pot still was estimated to yield 21.4 gallons per bushel of wet stillage with 9 percent dry matter. The other two on-farm and small community stills were estimated to yield 15.7 gallons per bushel of wet stillage composed of 12.3 percent dry matter. The two community stills producing DDGS were estimated to produce 17.8 pounds of DDGS at 10 percent moisture.

Because the small pot still would not produce a daily supply of wet stillage, it was assumed that the stillage would be fed to low production livestock and would have a value equivalent to hay. The other stills analyzed were based on continuous operations so that a daily stillage supply would be available. The long-term (15-year average) DDGS wholesale price at Cincinnati has been $130 per ton (1979 dollars). As prices paid by farmers for DDGS are not reported, the difference in wholesale and prices paid by farmers for soybean meal was used for estimating purposes. On a long-term basis, the prices paid by farmers for soybean meal has been about 28 percent above its Decatur wholesale price. This suggests that prices for on-or near-farm use of wet stillage should be higher than the equivalent wholesale price for DDGS.

Because the small pot still would not produce a daily supply of wet stillage, it was assumed that the stillage would be fed to low production livestock and would have a value equivalent to hay. The other stills analyzed were based on continuous operations so that a daily stillage supply would be available. The long-term (15 year average) DDGS wholesale price at Cincinnati has been $130 per ton (1979 dollars). Prices paid by farmers for DDGS are not reported. On a long-term basis this price has been about 28 percent above the Decatur wholesale price. This suggests that prices for on-or near-farm use of wet stillage should be higher than the equivalent wholesale price for DDGS.

The wet stillage material will require additional effort for handling and feeding than does soybean meal. For purposes of these estimates, DDGS prices equivalent to $153 per ton were used on the basis that the material would be used on the farm. The large on-farm and the small community, wet stills may or may not have on-site stillage feeding potentials. Consequently a lower price--$135 per ton--was used. DDGS from the two stills drying stillage was priced at $130 per ton. This is equivalent to the long-term wholesale price and was based on the assumption that these units would be competing in the national market for DDGS sales.

Because wet stillage is sometimes priced on a per gallon basis, the prices and conversion factors are summarized in Table VIII-2 for references.

3. Operating and Maintenance Costs

The operating and maintenance costs include labor, energy, electricity, other supplies (enzymes, yeasts, etc.), repairs and maintenance, taxes, insurance and general and administrative expense. The reader is referred to Chapter VII and associated appendix A for the basis of estimating these costs.

4. Capital Costs

The estimate of annual ethanol capital costs is not as straightforward as feedstocks, by-product credits, and operating and maintenance costs. These latter costs are expended annually whereas capital costs must reflect investment costs that are capitalized (amortized) and recovered over the life of the plant.

Table VIII-2. Stillage prices and conversions

Type of still	DDGS Price 10% moisture	Dry	Dry	Stillage per bushel Solids	Material	Stillage price
	($/ton)	($/ton)	($/lb)	(lbs)		($/gal)
Pot still	67	74	.037	16	21.4 1/	.028 4/
Small on-farm	153	170	.085	16	15.7 2/	.087 5/
Large on-farm	135	150	.075	16	15.7 2/	.076 6/
Small community, wet	135	150	.075	16	15.7 2/	.076 6/
Small community, DDGS	130	144	.072	16	17.8 3/	--
Large community, DDGS	130	144	.072	16	17.8 3/	--

1/ gallons $= \dfrac{16 \text{ lbs solids}}{(9 \text{ pct solids})} \bigg/ 8.3 \text{ lbs per gal}$

2/ gallons $= \dfrac{16 \text{ lbs solids}}{12.3 \text{ pct solids}} \bigg/ 8.3 \text{ lbs per gal.}$

3/ pounds $= \dfrac{16 \text{ lbs solids}}{90 \text{ pct solids}}$

4/ \$/gal $= \dfrac{16 \text{ lbs solids} \times \$.037 \text{ per pound}}{21.4 \text{ gal}}$

5/ \$/gal $= \dfrac{16 \text{ lbs solids} \times \$.085 \text{ per pound}}{15.7 \text{ gal.}}$

6/ \$/gal $= \dfrac{16 \text{ lbs solids} \times \$.075 \text{ per pound}}{15.7 \text{ gal.}}$

A common approach is to annualize capital costs as the sum of straight-line depreciation and an interest charge on average investment (investment divided by two). This method, as well as other approaches, to convert capital expenditures into an equivalent annual cost, fail to reflect key financial parameters including the depreciation method, capital structure, cost of debt, cost of equity, investment tax credits, federal and state income taxes, and inflation rates. The inclusion of all of these factors in a cost estimate is not straightforward and involves considerable computational effort.

Because of the computational effort, a financial model for estimating a capital recovery factor was formulated, programmed, and computer processed. The model, a discounted cash flow (sometimes called a life-cycle cost) model, reflected all of these factors and provided a capital cost recovery rate in terms of an average real cost in 1979 dollars.

The factors and resulting annual capital cost per gallon for the base case estimate are reported in Table VIII-3. A multiplication of the appropriate factor times the total investment, including working capital, gives the equivalent annual capital cost. Dividing this annual cost by the gallons of ethanol production gives the per gallon cost comparable to the other cost elements. It should be noted that a different capital recovery factor would be associated with any set of these factors that differs from those shown in Table VIII-3, that is with different feedstock costs, by-product credits, and operating and maintenance costs.

As a point of reference, the coefficients used in estimating small scale ethanol production are summarized in Table VIII-4.

B. Estimated Costs of Production

The preceding cost data indicate the estimated costs of producing ethanol. As shown in Table VIII-5, the estimated cost of producing 190 proof ethanol ranges from $1.63 to $1.13 per gallon for the on-farm units. It should be noted that these represent farm-gate costs. Costs of producing 200 proof ethanol in the community units range from $1.38 to $1.21 per gallon, depending on the presence of drying.

Care must be exercised in comparing these costs. The first three costs shown in Table VIII-5 are 190 proof ethanol and the latter three are for 200 proof alcohol. Too, the first four costs assume the direct use of wet stillage, a condition which eliminates drying costs. The effect of drying on costs is demonstrated by a comparison of the $1.21 per gallon for the small community, wet unit and the $1.38 per gallon for the small community DDGS unit. These additional costs for drying amount to $.17 per gallon of ethanol and consist of higher labor, energy and capital costs. The estimated by-product credit for wet stillage would be greater by the eliminated costs for drying or $.02 per gallon of ethanol. Capital costs increase significantly ($.05 per gallon of ethanol) with drying, owing to the rather high investment costs and energy inputs of dryers.

Table VIII-3. Factors used to estimate capital recovery factors for base case costs

Item	Unit	Model plant: Pot still	Small on-farm	Large on-farm	Small community wet	Small community DDGS	Large community DDGS
Investment value							
Facilities	$1,000	25.0	140.0	365.0	1,200.0	1,575.0	2,750.0
Working capital	$1,000	3.0	7.2	46.8	140.0	162.0	325.0
Total	$1,000	28.0	147.2	411.8	1,340.0	1,737.0	3,075.0
Facilities Investment Composition							
Land	Pct	0	0	0	1	1	3
Site	Pct	0	7	5	1	1	2
Buildings	Pct	0	0	5	4	3	5
Equipment	Pct	100	93	90	94	95	90
Plant life	Yrs	5	10	10	20	20	20
Capital structure							
Equity	Pct	50	50	50	50	50	50
Debt	Pct	50	50	50	50	50	50
Cost of capital							
Equity	Pct	14	14	14	14	14	14
Debt	Pct	12	12	12	12	12	12
Depreciation method	Straight line	SL	SL	SL	SL	SL	SL
Income tax rate	Pct	25	25	25	38	38	38
Investment tax credit rate	Pct	20	20	20	20	20	20
Inflation rate							
General	Pct	7	7	7	7	7	7
Energy	Pct	10	10	10	10	10	10
Capital cost factor							
Debt	Pct of capital	10.3	6.1	5.6	3.9	3.3	3.8
Equity	Pct of capital	9.7	5.6	8.4	7.8	8.0	8.4
Income taxes	Pct of capital	0.6	0.5	0.9	1.0	1.4	1.5
Total	Pct of capital	20.6	12.2	14.9	12.7	12.7	13.7
Capital cost	$/gal ethanol	.36	.30	.17	.17	.22	.19

Table VIII-4. Summary of estimating factors for base case costs

Item	Unit	Model plant: Pot still	Small on-farm	Large on-farm	Small community wet	Small community DDGS	Large community DDGS
Annual ethanol production							
192 proof	gal/yr	16,000	60,000	360,000	--	--	--
200 proof	gal/yr	--	--	--	1,000,000	1,000,000	2,000,000
Feedstock cost							
Ethanol yield, 192 proof	gal/bu	2.4	2.5	2.5	--	--	--
Ethanol yield, 200 proof	gal/bu	--	--	--	2.5	2.5	2.5
Price	$/bu	2.50	2.50	2.50	2.75	2.75	2.75
By-product credit							
Wet stillage yield, 9 pct solids	gal/bu	21.4			--	--	--
Wet stillage yield, 12.3 pct solids	gal/bu	--	15.7	15.7	15.7	--	--
DDGS	lb/bu	--	--	--	--	17.8	17.8
Wet stillage price, 9 pct solids	$/gal	.028			--	--	--
Wet stillage price, 12.3 pct solids	$/gal	--	.087	.076	.076	--	--
DDGS price	$/T	67	153	135	135	130	130
Labor							
Requirement	hrs/gal	.05	.04	.02	.010	.014	.007
Price	$/hr	3.00	5.00	6.00	6.00	6.00	6.00
Energy							
Requirement	MBtu/gal	43	43	41	61	82	82
Price	$/MMBtu	2.315	2.315	2.315	2.315	2.315	2.315
Electricity							
Requirement	kWh/gal	.5	.5	.5	.5	.5	.5
Price	$/kWh	.05	.05	.05	.05	.05	.05
Supplies	$/gal	.09	.09	.09	.09	.09	.09
Repairs and maintenance							
Through five years	Pct of equip. cost	3	3	3	3	3	3
After five years	Pct of equip. cost	5	5	5	5	5	5
Taxes and insurance	$/yr	1,000	5,400	15,800	41,100	52,700	88,300
General and administrative	$/yr	--	--	15,000	30,000	40,000	50,000
Capital cost	$/gal	.36	.30	.17	.17	.22	.19

Table VIII-5. Estimated costs of ethanol production 1979 dollars

Cost item	Pot still	Small on-farm	Large on-farm	Small community wet	Small community DDGS	Large community DDGS
	---($/190 proof gal)----			-------($/200 proof gal) -------		
Direct						
Feedstock	1.04	1.00	1.00	1.10	1.10	1.10
Labor	.15	.20	.12	.06	.08	.04
Energy	.10	.10	.09	.14	.19	.19
Electricity	.03	.03	.03	.03	.03	.03
Supplies	.09	.09	.09	.09	.09	.09
Subtotal	1.41	1.42	1.33	1.42	1.49	1.45
Indirect						
Repairs and maintenance	.05	.07	.03	.03	.04	.04
Taxes and insurance	.06	.09	.04	.04	.05	.04
General and administrative	.00	.00	.04	.03	.04	.03
Subtotal	.11	.16	.11	.10	.13	.11
By-product credit	(.25)	(.54)	(.48)	(.48)	(.46)	(.46)
Total operating	1.27	1.04	.96	1.04	1.16	1.09
Capital costs	.36	.30	.17	.17	.22	.19
Total cost	1.63	1.34	1.13	1.21	1.38	1.29

The cost estimates shown also provide some indication of economies of size for the two major situations shown. Costs per gallon decline from $1.63 for the small pot still (16,000 gallons per year) to $1.13 for the large on-farm unit (360,000 gallons per year). Comparison of the small and large community stills (1.0 million and 2.0 million gallons per year, respectively) with drying facilities also indicate economies of size for producing 200 proof ethanol.

1. Centralized Dehydration

While 190 or lower proof may be used directly as a liquid fuel, this quality of alcohol would have to be dehydrated to 200 proof to enter the gasohol market. A central dehydration unit serving satellite stills producing 190 proof ethanol could perform this process. The central plant would operate a collection service similar to a milk collection route. One man and one truck would make two pickups per day on a five day schedule collecting 2,500 gallons per trip of 190 proof ethanol from on-farm ethanol plants and transport the low proof ethanol to the control plant. The collections would be in an average ten-mile radius over a 42 week year and would transport the 1,053,000 gallons of 190 proof alcohol.

Such a plant with a cooking and fermentation capacity of 1.0 million and an additional capacity to process 1.0 million gallons from on-farm units would incur costs of $.17 per gallon of ethanol (see Table VIII-6). This cost added to those of producing 190 proof ethanol results in a 200 proof cost of $1.30 to $1.80 per gallon of ethanol depending on the source of ethanol. This results in 200 proof costs of close to those of 1.0 million gallon community still without stillage drying and the 2.0 million gallon still with stillage drying.

2. Lower Proof Ethanol

As indicated in Cahpter II, lower proofs can technically be used as a straight-ethanol fuel for spark ignition engines or for aspirating in diesel engines. The estimated costs of production for a small on-farm unit producing 160 proof ethanol compared to those for the small on-farm unit producing 190 proof are shown in Table VIII-7. The cost of production of $1.00 per gallon of 160 proof reflects the reduced investment required due to the elimination of one distillation column. Other direct and indirect costs were estimated analogously to those for the plants detailed in Appendix A. Adjusting the cost of $1.34 per gallon of 190 proof to 160 proof on an ethanol content basis give a cost of $1.13 per gallon. Production of 160 proof then is $.13 per gallon less than the cost if 190 proof ethanol is diluted.

Estimates of the cost of producing 100 proof ethanol indicate that a production cost of about $.62 per gallon is equal to the cost of 160 proof ethanol adjusted to 100 proof.

Table VIII-6. Estimated incremental costs for centralized dehydration of 190 proof ethanol

Cost item	Central dehydration
	($/200 proof gallon)
Direct	
Feedstock	--
Labor	.01
Energy	.05
Electricity	.01
Transportation	.01
Subtotal	.08
Indirect	
Repairs and maintenance	.01
Taxes and insurance	.01
General and administrative	.02
Subtotal	.04
By-product credit	--
Total operating	.12
Capital costs	.05
Total cost	$.17

Table VIII-7. Estimated costs of production of ethanol in a small on-farm still by proof level

Cost item	Small on-farm still	
	160 proof	190 proof
	($/gal)	
Direct		
Feedstock	.84	1.00
Labor	.17	.20
Energy	.06	.10
Electricity	.03	.03
Supplies	.08	.09
Subtotal	1.18	1.42
Indirect		
Repairs and maintenance	.04	.07
Taxes and insurance	.06	.09
General and administrative	--	--
Subtotal	.10	.16
By-product credit	(.45)	(.54)
Total operating	.83	1.04
Capital costs	.17	.30
Total cost	1.00	1.34

3. Comment

In considering these costs of production, the reader should keep in mind that they are based on the best information and knowledge available that very few units have actually been built, and that even fewer have operating data. Each individual and actual situation will present specific cost situations which will differ from these estimates.

C. Sensitivity Analyses

To provide additional perspective to these cost estimates and also to provide information to users to estimate costs for specific situations, sensitivity analyses were done for the major cost elements. This analysis involves re-estimating the ethanol production cost by varying one variable at a time while holding all other variables constant.

The results of those analyses are presented graphically for each of the model plants in Appendix B, Figures B-1 to B-12. To facilitate presentation, annual operating variables are shown in one figure and the equivalent capital costs are shown in the following figure for each model plant. The figure is designed with the per gallon cost of ethanol production on the vertical axis and the percent change in base case estimating factors shown in Table VIII-4 is indicated on the horizontal axis.

The slope of the lines indicate the relative impact of the variable. The steeper the slope, the greater the impact of cost changes by the indicated variable. Conversely, those variables with relatively little slope produce little impact on production costs.

It is also noted that these graphs can be used to estimate the cost of production with combined changes of several variables. This is done by multiplying the total base case cost times the ratio of the total cost (from interpolation) associated with the percentage change of the variable to the total base case cost. More specifically, the formula is as follows:

$$\text{New combined cost} = \text{Total base case cost} \times \frac{\text{Revised total cost for variable j}}{\text{Base case cost}} \times \frac{\text{Revised total cost j}}{\text{Base case cost}} \times \ldots \times \frac{\text{Revised total costs j}}{\text{Base case cost}}$$

The resulting estimate should be within one or two percent, depending on rounding error and the accuracy of interpolation.

Results of Sensitivity Analyses

Eleven variables were analyzed, including six operating and five capital variables. As can be seen in the graphs, operating variables were found to be more sensitive, that is, they affect production costs more than do capital costs. The specific list of variables and the relative effect of each is as follows:

Operating	Effect
Annual ethanol production	Large
Ethanol yield per bushel	Large
Feedstock price	Large
Wage rate	Small
Energy price	Small
By-product price	Large
Capital	
Plant investment	Large
Debt-equity proportions	Small
Interest rate	Small
Investment tax credit	Medium
Cost of equity	Small

The relatively large effect of production level, ethanol yield, feedstock price and by-product price would be expected. While all of these factors are important, feedstock prices dominate. A ten percent increase, i.e., \$.25 per bushel, raises total cost nearly \$.10 per gallon of ethanol or conversely a ten percent reduction reduces total ethanol cost about \$.10 per gallon. This is in contrast to a ten percent change in interest rates which affect total cost by about \$.01 per gallon of ethanol.

It is noted that of the capital cost factors, the investment tax credit and plant investment costs have the largest affect on total cost. However, relative to feedstock price, ethanol yields and production levels, the effect of tax credits and plant investment are relatively small.

D. Relationship of Production Costs to Fuel Value

To place the estimated costs of ethanol production in perspective, they should be compared with the fuel value of ethanol vis-a-vis the fuel for which ethanol potentially could substitute. Fuel values were estimated by applying the volumetric values developed in Chapter II to gasoline, diesel, and LPG prices as appropriate. Prices used reflect the prices of late 1979 and early 1980 paid by farmers for farm applications and consumers for consumer applications, i.e., gasohol. Four potential applications were examined including gasohol, straight alcohol, carbureting in diesel engines and crop drying.

1. Gasohol

As indicated in Chapter II, ethanol in 10 percent mixture with gasoline would have a value of 75 percent of gasoline. In addition there is the potential for an octane enhancement credit under certain conditions. If a base gasoline stock with a lower octane is available for gasohol blending or if there is a need for a higher octane fuel, a credit of about $.10 per gallon of ethanol would appear to be appropriate. However, a gasohol base stock is not likely to be available unless a large gasohol program emerges. With small local or regional programs, it is unlikely that a special base stock will be available. The need for higher octane is difficult to assess, for engine adjustments may produce the same result as the use of higher octane gasohol. If no octane enhancement credit was taken, the fuel value of 200 proof ethanol in gasohol would be $.64 per gallon, against a refinery gate unleaded regular gasoline price of $.85 per gallon. Assuming that dealer margins, transportation and terminal costs, and fuel taxes for ethanol and gasoline were equal, the difference between production costs and fuel value would be $.54 to $.74 per gallon of ethanol depending on distillery type. Where the octane enhancement credit was applicable, this difference would be decreased to $.44 to $.64 per gallon.

2. Straight Ethanol

As suggested in Chapter II, various approaches are available for using straight ethanol and include dual ethanol and gasoline systems and ethanol-only fuel systems. To illustrate the fuel value, the ethanol-only system was considered. With a weighted gasoline price of $.97 per gallon 1/ to the farmer on a bulk basis and net of taxes, the ethanol fuel value for various proofs would be as follows:

Proof	Ethanol fuel value ($/gal)
200	.74
190	.64
160	.49

Use of 190 proof ethanol, with production costs of $1.13 to $1.63 per gallon in this matter, would result in costs exceeding fuel value by $.49 to $.99 per gallon.

3. Carbureting Ethanol into Diesel Engines

Of the potential diesel applications, aspiration appears to be the most feasible in the near term. Assuming an on-farm diesel price of $.90 per gallon, the fuel value of ethanol would be as follows:

1/ Assumes $.85 per gallon refinery gate price for unleaded regular, $.80 per gallon for leaded regular, $.07 per gallon bulk dealer markup, $.08 per gallon transportation and terminal costs, 40 percent unleaded and 60 percent leaded gasoline.

Proof	Ethanol fuel value ($/gal)
200	.50
190	.46
160	.40
120	.30
100	.25

The volumetric value estimates shown in Chapter II indicate that on this basis the costs of 190 proof ethanol would exceed its fuel value by $.66 to $1.17 per gallon, depending on the type and size of still. The 100 proof ethanol cost would exceed its fuel by $.37 per gallon at a base cost of $1.30. Larger stills with lower costs might reduce this difference to about $.20 per gallon.

4. Grain Drying

Of the other possible fuel applications for ethanol, grain drying appears to be the most promising. While there is little research on this application, it appears technically feasible. Assuming LP gas prices of $.55 per gallon delivered to the farm, 200 proof ethanol would exceed the fuel value of $.51 per gallon. This would mean that production costs would have a fuel value of $.70 to $.87 per gallon of ethanol in this application, depending on the type of production facility.

5. Summary

Of the four types of applications examined here, the costs of production through small scale ethanol plants exceeded fuel in all cases, although the extent of difference depends on the cost of production and application. These estimates are based on a heat value basis excepting the potential octane credit for gasohol. While claims of improved performance from ethanol can be found, research available to date does not justify the inclusion of credits for straight ethanol or its fumigation into diesel engines. If evidence is found to support credits for ethanol, clearly these estimates would need to be modified.

APPENDIX A

MODEL ETHANOL PLANTS

A. Pot Still Model Ethanol Plant

This model is the simplest of all ethanol plants and represents a commercial model of the legendary moonshiner's pot still. This model may even be considered a learner's plant by which a farmer or other operator may learn the techniques of operation and acquire the experience required to proceed to a larger continuous still that will be more a sophisticated and more efficient fuel producing unit.

1. Type and Size of Operation

A pot still usually will be operated by one person who will prepare the mash, cook, and ferment in one tank on a three-day cycle. On the first day the mash will be prepared by cooking and treating with enzymes and then left to ferment, largely unattended, for 2 or 3 days. On the third day when the mash reaches an alcohol level of 7 to 10 percent, the operator will distill the mash in a single or double column still to produce 160 to 190 proof ethanol and wet stillage. Thus, every third to fourth day or twice a week, the operation will produce ethanol. The operator will then recharge the cook tank for the next batch. A typical, commercially available still will produce about 160 gallons of alcohol per batch. If operated regularly and year-round, the annual production would be 16,000 gallons.

2. Location

This model plant probably will be located on a farm in the open or in a building, depending on the climate and weather protection required. Its process and some of its cooling water will come from a well or similar supply. Some cooling water may come from a stream or pond.

3. Feedstock

The mash will be prepared from shelled corn or other grain or from sample grade grains that may be obtained on farm or locally at below market prices.

4. Type and Use of Products

The primary product, ethanol, at 160 to 190 proof, will be used for on the farm as fuel for vehicles (properly converted for alcohol fuel use), space heating, cooking, grain drying, and other farm liquid fuel requirements. Some excess product may be sold "as is" to neighbors or to a community plant capable of further processing the alcohol to 200 proof for use in the gasohol market.

The secondary product, wet stillage, because of the probable intermittent production of a pot still will be available about twice a week for feed use for low production animals. If such feed uses are not available, the wet stillage may be distributed on the land for its value as fertilizer.

5. Investment Costs

Some pot stills may be farmer built from miscellaneous materials with a cost that may vary from a few thousand to $10.000. However commercial plants either skid or trailer-mounted,are expected to cost about $15,000 for the major parts with an additional $10,000 required for storage tanks (grain and alcohol) and other test and auxilliary equipment. The total model plant is estimated at $25,000 and has an expected life of 5 years.

6. Operating Costs

Operating costs are the direct cost and the indirect costs of converting corn to 190 proof ethanol. Costs do not include grain costs or the value of the by-product stillage. These are evaluated in Chapters V and VI.

a. Direct costs

The direct costs are those directly related to the amount of ethanol produced and include labor, fuel, electricity,and supplies of yeast, enzymes, and other chemicals.

Labor. For the pot still, it is assumed that one part-time person will operate the plant while carrying out other farm operations. While some operators may choose to declare this intermittent labor to have no value, it has been assumed here that three hours of labor will be required for each batch of 160 gallons or .05 man hours per gallon of ethanol. A minimal, low-hourly rate of $3.00 per hour has also been assumed so that the labor per gallon is calculated at $.15.

Fuel. A hand-fired coal or wood burning boiler has been assumed; the operator will stoke and regulate the steam pressure while the cooking and distillation operations are underway. The energy required to produce steam for cooking and distilling is estimated as follows:

Operation	Btu/gal 190 proof
Cooking	4,000
Distillation	30,000
Miscellaneous	9,000
Total	43,000

This amount of steam requires a 25 horsepower boiler (80 percent efficient). If coal has a heat content of 11,000 Btu per pound and costs $40 per ton, the fuel cost for this model plant will be $.10 per gallon.

Electricity. The electrical energy needed to operate the grinder, augers, mixers, and pumps for the complete plant has been estimated to be 0.5 kWh per gallon. Assuming an electrical rate of $.05/kWh the electricity cost per gallon is $.03.

Supplies. An alpha-amylase is used in the cooking process to gelatinize the starch. At a price of $1.75 per lb for this enzyme the cost per bushel of grain will be $.0595. The glucoamylase enzyme used to convert starch to sugar is priced at $2.63 per liter and costs $.08925 per bushel. A commercial dry yeast for fermentation is priced at $.90 per lb and cost $.054 per bushel. These 3 supplies total $.20 per bushel of grain; thus, if the theoretical yield of alcohol is 2.6 gallons per bushel the per gallon cost of the items is .08. An additional $.02 per gallon cost has been assumed to cover the miscellaneous chemicals needed for cleaning, sterilizing, and for adjusting the pH of the mash and treating the boiler feedwater. The total cost for supplies is $.09 per gallon.

b. Indirect costs

Indirect costs are annual costs not closely related to production. These include: maintenance, general and administrative, property taxes, insurance, tax bond, and depreciation costs. For the pot still, it has been assumed that general and administrative costs are part of the farm operation and no specific cost for this function has been assigned.

Maintenance. Maintenance costs for this operation have been assumed to be 3 percent of the investment cost. Prorated over 16,000 gallons of product, maintenance cost is $.05 per gallon.

Insurance. Four types of insurance should be carried by a small still operator. The rates and costs shown below will vary from state to state and will also vary among insurance companies. These costs are estimated to be:

Insurance type	Rate	Annual premium
General Liability $500,000 coverage	$.65/$100 payroll	$ 15.60
Product liability	$1.00/$1,000 sales	12.90
Workmen's compensation State of Kansas	$4.93/$100 payroll	118.30
Fire and extended coverage	$.80/$100 valuation	200.00
	Total	$ 346.80

$346.80/16,000 gallons = $.02/gal

Taxes. The property taxes will vary by country and by state. For purposes of this report,two assumptions have been made: the tax valuation will be based on 20 percent of the fair market value (investment cost of equipment) and the tax rate will be 100 mills per dollar of valuation. Thus for this model plant the valuation is $5,000 and the annual tax is $500 or $.03 per gallon of ethanol.

Tax Bond. According to current regulations, the holder of a Bureau of Alcohol, Tobacco and Firearms (BATF) commercial permit must post a bond equivalent to the tax of $10.50 per proof gallon (100 proof) on 15 operating days of alcohol production. For this plant 15 days of production is 640 gallons of 190 proof or 1,216 proof gallons. At $10.50 per proof gallon, the bond required is approximately $13,000. The bond rate quoted now is $12.00/$1,000 of tax liability or $156 per year and the per gallon cost is .01 per gallon.

Depreciation. The depreciation cost is important only for calculating income tax and, therefore, in the financial analysis shown in the preceding portion of this report, it is part of capital recovery. However the depreciation figure used for calculating the cost of converting corn to alcohol is based on the estimated life of the equipment. For this model plant, 5 years is the estimated life and the depreciation rate is 20 percent per year. For this plant then, depreciation is $5,000 divided by 16,000 gallons or .31 per gallon of ethanol.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gal)
Direct		
Labor	2.4	.15
Fuel	1.6	.10
Electricity	.4	.03
Supplies	1.4	.09
Total	5.8	.37
Indirect		
Maintenance	.8	.05
General and administrative	--	--
Taxes	.5	.03
Insurance	.3	.02
Tax Bond	.2	.01
Total	1.8	.11

B. Small On-Farm Model Ethanol Plant

The key characteristic of the small on-farm model plant is its multiple fermentation tanks which permit the continuous fermentation and distillation of ethanol for 6 days per week. The plant equipment will be purchased as a package unit for small-scale, on-the-farm ethanol production.

1. Type and Size of Operation

This plant will feature a continuous batch fermentation process that will result in 6 eight-hour days of distillation at the rate of 25 gallons of 190 proof ethanol per hour. The operation of the plant will require one full time operator six days per week, and when operated for 300 days per year, it will result in approximately 60,000 gallons of ethanol product. The distillation will be carried out on one shift only; fermentation will continue around the clock unattended for 16 hours per day for 6 days and for 24 hours on the 7th day.

2. Location

A building is required for this type and size of plant. Cooling and process water will be drawn from existing wells and ponds.

3. Feedstock

Feedstock will be locally grown and stored corn or similar grain unless there is an opportunity to obtain sample grade or damaged grains nearby.

4. Type and Use of Product

It is assumed that approximately half of this plant's 60,000 annual gallons of 190 proof ethanol will be used on the farm and half will be sold locally in a 190 proof market or to a commercial plant for upgrading to 200 proof.

The by-product, wet stillage, will be integrated into a continuous feeding program of high production livestock and none will be dried or sold. Good management of by-product use will be required to have a supply available on the day when there is no distillation.

5. Investment Cost

The investment costs for this on-the-farm ethanol plant have been made with the following assumptions:

a) no land cost--by using land of existing farmstead
b) no grain storage cost--by using existing storage
c) no feedstock preparation equipment--by using feed grinder now on farm
d) no water supply cost--by using existing wells and/or ponds and pumps in place
e) no building cost--by using an existing building

The other costs that are included as investment costs are estimated from the tentative prices of packaged ethanol plants offered for sale by current manufacturers. The summary of investment costs are:

Site preparation	$10,000
Supply storage	1,000
Boiler (gas fired)	30,000
Cooking equipment	2,000
Fermentation tanks (6)	12,000
Instrumentation	5,000
Stripping column (12" x 20')	15,000
Rectification column (12" x 20')	15,000
Denaturization equipment	2,000
Alcohol storage (5,000 gallons)	2,000
Stillage storage	2,000
Miscellaneous	15,000
Subtotal	111,000
Erection and installation (25%)	29,000
Total investment cost	$140,000

The above costs assume that the cooking, fermentation, and storage tanks and the columns will be fabricated from mild carbon steel.

6. Operating Costs

Operating costs are those direct and indirect costs to convert corn to 190 proof alcohol at the rate of 25 gallons per hour. These costs do not include the feedstock (corn) costs nor the value of the wet stillage for livestock feeding. These costs will be similar for all model plants and are evaluated elsewhere in the report.

a. Direct costs

The direct costs are those related to the number of gallons of ethanol produced and are labor, fuel, electricity and supplies.

Labor. This plant will require one full-time person working 8 hours per day for 6 days a week. On a per gallon basis, .04 man hours will be required at an assumed rate per hour of $5.00 per hour or $.20 per gallon.

Fuel. Energy use is estimated to be 43,000 Btu per gallon; with a 60 horse-power natural gas boiler. With a gas price of $2 per mcf, the cost of 1,000 Btu, assuming an 80 percent efficiency, will be $.0023. This fuel cost is $.10 per gallon of ethanol produced. The heat required has been derived from these calculations:

Operation	Btu/gal (190 proof)
Cooking	4,000
Distillation	30,000
Miscellaneous	9,000
Total	43,000

Electricity. The electrical energy needed to operate the grinder, augers, mixers and pumps for this plant is estimated at 0.5 kWh per gallon. The assumed electrical rate per kWh is $.05; the electrical cost is $.03 per gallon.

Supplies. The alpha-amylase enzyme used in cooking starch is priced at 1.75 per lb and .03 lbs is used per bushel; hence, the cost is $.0595 per bushel of grain. The glucoamylase enzyme used to convert starch to sugar is valued at $.08925 per bushel based on a commercial price of $2.63 per liter. Dry, powdered yeast for the fermentation process is priced at $.90 per lb or $.054 per bushel of corn. These supplies total $.20 per bushel of corn and with an estimated yield of 2.6 gallons per bushel, the per gallon cost is $.08. An additional $.01 per gallon cost of acid, base and other chemicals make the total supply cost $.09 per gallon.

b. Indirect costs

Indirect costs are annual costs and are relatively independent of ethanol produced: maintenance, general and administrative expense, property taxes, insurance, tax bond cost and depreciation. For this plant, the general and administrative expense are considered a part of the total farm operation. No cost has been assumed for this function.

Maintenance. The annual cost for maintenance has been calculated to be 3 percent of the equipment investment cost for the first 5 years and 5 percent for the next 5 years.

Insurance. Four types of insurance are needed. The insurance rates will vary from company to company and state by state; however, for estimation purposes, the following rates were used:

Insurance type	Rate	Annual premium
General liability $500,000 coverage	$.65/$100 payroll	$ 78.00
Product liability	$1.00/$100 sales	48.60
Workmen's compensation	$4.93/$100 payroll	591.60
Fire and extended coverage	$.80/$100 sales	1,120.00
Total annual premium		$ 1,838.20

$1,838.20/60,000 gallons = $.03 per gallon

Taxes. Although taxes will vary by county and by state, two simplifying assumptions have been made for this report in order to estimate the tax cost. First, it has been assumed that tax valuation will be based on 20 percent of fair market value (i.e., equipment investment cost). Secondly, that the tax will be 100 mills on each dollar of valuation. For this model plant, the tax valuation will be $28,000 and the tax, $2,800 per year, or $.05 per gallon of ethanol.

Tax Bond. According to current regulations, a holder of a BATF commercial permit must post a bond equivalent to the tax of $10.50 per proof gallon (100 proof) on 15 days alcohol production. For this plant a 15 days production in proof gallons is 6,316 gallons with a tax liability of $66,000. The cost of a tax bond in this amount is $792 per year (based on a premium of $12.00/$1,000 bond) or $.01/gallon of production.

Depreciation. The calculation of this cost is important only for income tax calculation. From preceding financial analyses sections, depreciation is shown as a part of the capital recovery. However the expected life of the equipment is a key determinant in calculating depreciation and capital recovery. For this plant, a 10-year life has been assumed or a depreciation rate of 10 percent. With the investment cost of $140,000, the depreciation is $14,000 annually or $.23 per gallon.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gal)
Direct		
Labor	12.0	.20
Fuel	6.0	.10
Electricity	1.5	.03
Supplies	5.4	.09
Total	24.9	.42
Indirect		
Maintenance	3.9	.07
General and administrative	--	--
Taxes	2.8	.05
Insurance	1.8	.03
Tax bond	0.8	.01
Total	9.3	.16

C. Large On-Farm Ethanol Plant

This model is a farm-located, continuous fermentation and distillation process. It is the largest farm ethanol plant illustrated and produces 190 proof ethanol and wet stillage.

1. Type and Size of Operation

Operating continuously, 24 hours per day, 7 days per week and 300 days per year at a rate of 50 GPH, this plant is capable of producing 360,000 gallons annually. Four shifts of operators will be required to man this continuously operating plant.

2. Location

The plant will probably be located on a farm; however, it could be considered a small community or cooperative still. Relatively elaborate site preparation, building and storage facilities will be required and the availability of an adequate water supply will be a key location consideration.

3. Feedstock

The feedstock will be locally grown and stored corn or similar grain unless purchasable sample or damaged grain is nearby.

4. Type and Use of Products

Of the 360,000 gallons of 190 proof ethanol produced by this model plant, it is assumed that one half will be consumed in other farm activities and one half will be sold in local markets. The wet stillage will be fed to high production livestock on a continuous basis. The third product, carbon dioxide, is presumed to have no local use and will be vented.

5. Investment Cost

No land cost is included on the assumption that this ethanol plant will be part of the farmstead. Storage, feedstock preparation equipment, and suitable building costs are included in the cost estimated. The equipment for fermentation and distillation plus the instrumentation for control of these processes will be purchased as a package from the manufacturer. Design, engineering and erection costs will be considerably less than that for custom-designed and built equipment.

Summary of Investment Costs - 1979

Items	Costs ($000)
Site preparation	20
Building	20
Receiving and storage	20
Supply storage	2
Feedstock preparation	15
Water supply	5

Items	Costs ($000)
Boiler	35
Cooking	5
Fermentation	36
Instrumentation	15
Distillation	25
Rectification	25
Denaturization	2
Alcohol storage	3
Stillage storage	2
Miscellaneous	15
Subtotal	245
Engineering and erection	120
Total investment cost	365

6. Operating Costs

Operating costs are considered to be those direct costs and indirect costs to convert corn to 190 proof alcohol at the rate of 50 gallons per hour. These costs do not include the feedstock (corn) costs or the value of the wet stillage for livestock feeding for these costs are similar for all model plants and are evaluated elsewhere in the report.

a. Direct costs

The direct costs are those directly related to the number of gallons of ethanol produced and are labor, fuel, electricity and supplies.

Labor. This plant requires one full time person working 8 hours per shift for 4 shifts. On a per gallon basis, .02 man hours will be required at an assumed rate per hour of $6.00 or $.12 per gallon.

Fuel. To calculate the fuel cost for the boiler, the model assumes a 43,000 Btu per gallon heat requirement for a 50 horsepower natural gas boiler. Such a boiler will require $.0023 worth of fuel per 1,000 Btu, assuming an 80 percent efficiency. This fuel cost is $.09 per gallon of ethanol produced. The heat required has been derived from these calculations:

Operation	Btu/gal. 190 proof
Cooking	4,000
Distillation	30,000
Miscellaneous	9,000
Total	43,000

Electricity. The electrical energy needed to operate the grinder, augers, mixers and pumps for this plant is estimated at .5 kWh per gallon. The assumed electrical rate per kWh is .05 or rounded to $.03 per gallon.

Supplies. The alpha-amylase enzyme used in cooking starch is currently priced at 1.75 per lb; at a rate of .03 lbs per bushel, cost is $.0595 per bushel of corn. The glucoamylase enzyme used to convert starch to sugar costs $.08925 per bushel based on its commercial price of $2.63 per liter. Dry, powdered yeast for the fermentation process is priced at $.90 per lb or $.054 per bushel of corn. These supplies total $.20 per bushel of corn and, with an estimated yield of 2.6 gallons per bushel, the per gallon cost is $.08. An additional .01 per gallon cost of acid, base, and other chemicals make the total supply cost .09 per gallon.

b. Indirect costs

Indirect costs are annual costs relatively independent of production: maintenance, general and administrative expense, property taxes, insurance, tax bond cost and depreciation.

Maintenance. The annual cost for maintenance has been estimated at 3 percent of the equipment investment cost for the first 5 years and 5 percent thereafter.

Insurance. Four types of insurance are needed. The insurance rates will vary from insurance company to company and state by state. However, for estimation purposes, rates quoted by a Midwestern firm have been used for the following calculations:

Insurance type	Rate	Annual premium
General liability $500,000 coverage	$.65/$100 payroll	$ 304.20
Product liability	$1.00/$100 sales	583.20
Workmen's compensation	$4.93/$100 payroll	2,307.00
Fire and extended coverage	$.80/$100 sales	2,920.00
Total annual premium		$6,114.40

$6,114.40/360,000 gallons = $.02 per gallon

Taxes. Although taxes will vary by county and by state, two simplifying assumptions have been made for this report in order to estimate the tax cost. First, it has been assumed that tax valuation will be based on 20 percent of fair market value (i.e., equipment investment cost). Second, the tax will be 100 mills on each dollar of valuation. For this model plant, the tax valuation will be $73,000 and the tax $7,300 per year or $.02 per gallon of ethanol.

General and Administrative. The general and administrative expense for this plant is $15,000 which is estimated to cover the cost of one person's time for managing the plant and marketing the products.

Tax Bond. According to current regulations, a holder of BATF commercial permit must post a bond equivalent to the tax of $10.50 per proof gallon (100 proof) and 15 days alcohol production. For this plant, 15 days production in proof gallons is 31,580 gallons with a tax liability of the maximum $200,000. The cost of a tax bond in this amount is $2,400.00 per year based on a premium of $12.00/$1,000 bond. On a cost per gallon basis, the tax bond is $.007/gallon of production.

Depreciation. The calculation of this cost is important only for income tax calculation. From preceding financial analysis sections, depreciation is shown as a part of the capital recovery. However, the expected life of the equipment is a key determinant in calculating depreciation and capital recovery. For the plant shown in the model size, 10 years has been assumed as the life of the plant, a depreciation rate of 10 percent. With the investment cost of $365,000, the depreciation is $36,500 annually or $.10 per gallon.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gal)
Direct		
Labor	43.2	.12
Fuel	34.2	.09
Electricity	9.0	.03
Supplies	32.4	.09
Total	118.8	.33
Indirect		
Maintenance	10.0	.03
General and administrative	15.0	.04
Taxes	7.3	.02
Insurance	6.1	.02
Tax Bond	2.4	.00
Total	40.8	.11

D. Small Community, Wet

This model plant is assumed to be a community or co-op operated plant not part of a farm enterprise. This model produces about 1 million gallons annually of anhydrous ethanol (200 proof).

1. Type and Size of Operation

On a basis of a 24 hour day, 300 days per year operation at the rate of 150 gallons per hour, this plant has capacity for about 1 million gallons of 200 proof ethanol. This size of operation is considered a commercial or industrial plant with hired management and has custom designed and installed equipment.

2. Location

It is expected that a plant of this size and type of operation will be located on the edge of a rural community, very likely near a feedlot, a petroleum processor or distributor, or both. Water availability will be a prime consideration in locating this plant and, therefore, the availability of adequate water, surface and/or groundwater is essential.

3. Feedstock

The feedstock will be purchased from a local grain elevator with the possibility that there may be an occasional opportunity to obtain sample grade or damaged grains nearby.

4. Type and Use of Product

The major product, 1 million gallons of 200 proof ethanol will be sold in the gasohol market by contract with a nearby petroleum refiner or distributor. The secondary product, stillage, will likewise be contracted to nearby feedlots for cattle or hogs.

5. Investment Cost

A modest land cost of $10,000 included in the investment cost for this model plant on the assumption that the plant will be located in conjunction with either a feedlot or a petroleum processing or distributing operation. Costs for other equipment have been estimated on the basis of custom design fabrication and installation as a turnkey project.

Summary of Investment Costs

Item	Cost ($000)
Land	10.0
Site preparation	10.0
Building	54.0
Receiving and storage	71.0
Supply storage	5.0
Feedstock preparation	11.0
Water supply	12.5
Boiler (coal fired)	175.0
Cooking	21.0
Fermentation	111.0
Instrumentation	40.0
Distillation	44.0
Rectification	31.0
Dehydration	78.0
Denaturization	3.0
Alcohol storage	4.0
Stillage storage	85.0
Wastewater treatment	10.0
Miscellaneous	20.0
Subtotal	795.5
Engineering and erection	404.5
Total investment cost	1,200.0

6. Operating Costs

Operating costs are considered to be those direct and indirect costs to convert corn to 200 proof alcohol at a continuous rate of 150 gallons per hour. These costs do not include the feedstock (corn) costs or the value of the concentrated wet stillage for livestock feeding. These have been evaluated elsewhere in the report.

a. Direct costs

The direct costs are those directly related to the number of gallons of ethanol produced and are labor, fuel, electricity and supplies.

Labor. This plant will require two full-time persons working 8 hours per day for two shifts and one person each for the other two shifts per week. On a per gallon basis, .010 man hours will be required at an assumed rate per hour of $6.00 per hour, a $.06 per gallon rate.

Fuel. An estimated 61,000 Btu per gallon heat is required in a 300 HP coal (or combination coal, wood or natural gas) boiler. Such a boiler will require $.0023 worth of fuel per 1,000 Btu, assuming an 80 percent efficiency and using 11,000 Btu coal delivered at the site for $40.00 per ton. This fuel cost is $.14 per gallon of ethanol produced. The heat required has been derived from these calculations.

Operation	000 Btu/gal 190 proof
Cooking	3.6
Distillation	28.0
Dehydration	20.0
Miscellaneous	9.4
Total	61.0

Electricity. The electrical energy needed to operate the grinder, augers, mixers and pumps for this plant is estimated at .5 kWh per gallon. The assumed electrical rate per kWh is .05 or rounded to $.03 per gallon.

Supplies. The alpha-amylase enzyme used in cooking starch is priced at 1.75 per lb at current commercial rates or $.03 lbs per bushel or $.0595 per bushel of corn. The glucoamylase enzyme used to convert starch to sugar is valued at $.08925 per bushel based upon a commercial price of $2.63 per liter. Dry, powdered yeast for the fermentation process is priced at $.84 per lb or $.05 per bushel of corn. These supplies total $.20 per bushel of corn and, with an estimated yield of 2.6 gallons per bushel, the per gallon cost is $.08. An additional .01 per gallon cost of acid, base and other chemicals make the total supply cost of .09 per gallon.

b. Indirect costs

Indirect costs, annual costs which are relatively independent of production, are maintenance, general and administrative expenses, property taxes, insurance, tax bond, and depreciation costs.

Maintenance. The annual cost for maintenance has been estimated to be 3 percent of the equipment investment cost for the first 5 years and 5 percent thereafter.

General and administration. The estimated cost for management and marketing for this plant (general and administration) is based on a cost of two full-time persons, an annual cost of $30,000 per year total or $.03 per gallon.

Insurance. There are four types of insurance to protect the financial interest of the enterprise and, therefore, these insurance costs are a part of the cost of ethanol production. The insurance rates will vary from insurance company to company and state by state. However, for estimation purposes, rates quoted for a Midwestern location have been used for the following calculations:

Insurance Type	Rate	Annual Premium
General liability $500,000 coverage	$.65/$100 payroll	$ 390.00
Product liability	$1.00/$100 sales	1,740.00
Workmen's compensation	$4.93/$100 payroll	2,958.00
Fire and extended coverage	$.80/$100 valuation	9,600.00
Total annual premium		$14,688.00

$14,688/1,000,000 gallons = .01 per gallon

Taxes. Although taxes will vary by county and by state, two simplifying assumptions have been made for this report in order to estimate the tax cost. First, it has been assumed that tax valuation will be based on 20 percent of fair market value (i.e., equipment investment cost). Second, the tax will be 100 mills on each dollar of valuation. For this model plant, the tax valuation will be $240,000 and the tax, $24,000 per year or $.02 per gallon of ethanol.

Tax bond. According to current regulations, a holder of a BATF commercial permit must post a bond equivalent to the tax of $10.50 per proof gallon (100 proof) on 15 days alcohol production. For this plant, 15 days production in proof gallons is 108,000 gallons with a tax liability in excess of $200,000 the maximum tax bond required. The cost of a tax bond in this amount is $2,400 per year based on a preimum of $12.00/$1,000 or $.002/gallon of production.

Depreciation. The calculation of this cost is important only for income tax calculation. From preceding financial analyses sections, depreciation is shown as a part of the capital recovery. However, the expected life of the equipment is a key determinant in calculating depreciation and capital recovery. For the plant shown in this model size, 20 years has been assumed as the life of the plant which makes the depreciation rate 5 percent. With the investment cost $1,200,000, the depreciation is $60,000 annually or $.06 per gallon.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gallon)
Direct		
Labor	60.0	.06
Fuel	141.2	.14
Electricity	25.0	.03
Supplies	90.0	.09
Total	316.2	.32
Indirect		
Maintenance	33.8	.03
General and administrative	30.0	.03
Taxes	24.0	.02
Insurance	14.7	.01
Tax bond	2.4	.01
Total	104.9	.10

E. Small Community DDGS

This model is a variation of the last previous model and was developed to show the change in operating costs of a plant when the additional cost of drying stillage (DDGS) is added to the cost of ethanol production. This plant is identical except that the costs both in investment and in operations associated with drying the stillage are added to and reflected in the ethanol cost per gallon.

1. Type and Size of Operation

On a 24 hour per day, 300 days per year operation, at the rate of 150 gallons per hour, this plant has a capacity for about 1 million gallons of 200 proof ethanol. This size operation is considered a commercial or industrial plant with hired management and custom designed and installed equipment.

2. Location

It is expected that a plant of this size and type operation will be located on the edge of a rural community, very likely near a feedlot and a petroleum

processor or distributor or both. Water availability will be a prime consideration in locating this plant and, therefore, the availability of adequate surface and/or groundwater is essential.

3. Feedstock

The feedstock will be purchased from local grain elevators. Occasionally sample grade or damaged grains may be available nearby.

4. Type and Use of Product

The major product will be 200 proof ethanol. The by-product, DDGS, will have a broad market and, because it is a dried product, will be of a type that can be shipped over great distances to reach national or world markets.

5. Investment Costs

In addition to the investment of equipment shown in the small community, wet model, added costs for the dryer and a larger boiler (including installation) will amount to $375,000. This addition makes the total investment cost $1,575,000.

6. Operating Costs

The operating costs for this model plant will remain the same as the previous model plant with the exceptions of those items listed below.

Labor. This plant will require two full-time persons working eight hours per day for each of the four weekly shifts. On a per gallon basis, .0139 man hours will be required at an assumed rate of $6.00 per hour or $.08 per gallon.

Fuel. Fuel costs for the stillage drying will add 21,000 Btu per gallon to the fuel requirements of the previous model. This additional fuel will add $.05 per gallon to those costs and will make the total fuel cost for this model plant to be $.19 per gallon for the total 82,000 Btu per gallon. The boiler will be a 400 HP boiler.

Maintenance. The cost of maintenance is assumed to be 3 percent of the equipment investment cost for the first five years and 5 percent thereafter.

General and administration. These overhead costs for this plant are based on the requirement of two full-time persons at a total of $40,000 per year or .04 per gallon of ethanol output.

Insurance

Insurance Type	Rate	Annual Premium
General liability $500,000 coverage	$.65/$100 payroll	$ 520.00
Product liability	$1.00/$100 sales	1,740.00
Workmen's compensation	$4.93/$100 payroll	3,944.00
Fire and extended coverage	$.80/1,000 valuation	12,600.00
Total annual premium		$ 18,804.00

$18,804/1,000,000 gallons = $.02 gallon

Taxes. The tax valuation is $315,000 for this plant so that the tax based on 100 mills per dollar of value will be $31,500 or rounded to $.03 per gallon.

Tax bond. According to current regulations, a holder of a BATF commercial permit must post a bond equivalent to the tax of $10.50 per proof gallon (100 proof) on 15 days alcohol production. For this plant, 15 days production in prooof gallons is 108,000 gallons with a tax liability in excess of $200,000, the maximum tax bond required. The cost of a tax bond in this amount is $2,400 per year based on a premium of $12.00/$1,000 or $.002/gallon of production.

Depreciation. With the investment cost at $1,575,000 for a 20 year life, the depreciation per gallon for this plant is $.08.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gallon)
Direct		
Labor	84.0	.08
Fuel	190.0	.19
Electricity	25.0	.03
Supplies	90.0	.09
Total	389.0	.39
Indirect		
Maintenance	44.9	.04
General and administration	40.0	.04
Taxes	31.5	.03
Insurance	18.8	.02
Tax bond	2.4	.00
Total	137.6	.13

F. Large Community, DDGS

This model plant is a community or co-op operated plant and produces 2 million gallons annually of anhydrous ethanol (200 proof). This model also assumes the sale of a dried by-product, DDGS.

1. Type and Size of Operation

On a 24-hour day, 300 days per year operation at the rate of 300 gallons per hour, this plant has the capacity for 2 million gallons of 200 proof ethanol. This operation is considered a commercial or industrial plant with hired management and custom designed and installed equipment.

2. Location

It is expected that a plant of this size and type operation will be located on the edge of a rural community, very likely near a feedlot and a petroleum processor or distributor or both. Water availability will be a prime consideration in locating this plant; therefore, the availability of adequate water from rainfall, surface, or groundwater is essential.

3. Feedstock

The feedstock for the mash will be purchased from local grain elevator storage. Occasionally damaged grains may be obtained locally.

4. Type and Use of Product

The major product, 2 million gallons of 200 proof ethanol, will be sold into the gasohol market by contract with a nearby petroleum refiner or distributor. The secondary product, DDGS, will be sold as a commodity on the national market.

5. Investment Cost

Land cost is included in the investment cost for this model plant on the assumption that the plant will be located separately but near either a feedlot or a petroleum processing or distribution operation. Costs for other equipment have been estimated on the basis of custom design fabrication and installation as a turnkey project.

A summary of these investment costs are as follows:

Item	Cost ($000)
Land	90.0
Site preparation	45.0
Building	135.0
Receiving and storage	90.0
Supply storage	10.0
Feedstock preparation	50.0
Water supply	40.0
Boiler (coal fired)	295.0
Cooking	40.0
Fermentation	200.0
Instrumentation	70.0
Distillation	50.0
Rectification	40.0
Dehydration	100.0
Denaturization	5.0
Alcohol storage	8.0
Stillage storage	100.0
Drying	400.0
Wastewater treatment	20.0
Miscellaneous	40.0
Subtotal (Equipment)	1,820.0
Engineering and erection	922.0
Total investment cost	2,750.0

6. Operating Costs

Operating costs are considered to be those direct costs and indirect costs needed to convert corn to 200 proof alcohol at a continuous rate of 300 gallons per hour. These costs do not include the feedstock (corn) costs or the value of the concentrated wet stillage for livestock feeding. These costs have been evaluated elsewhere in the report.

a. Direct costs

The direct costs are those directly related to the number of gallons of ethanol produced and are labor, fuel, electricity and supplies.

Labor. This plant will require two full-time persons working eight hours per day on each of four weekly shifts operating continuously the rated output of this plant. On a per gallon basis, .0069 man hours will be required at an assumed rate per hour of $6.00 per hour or $.04 per gallon.

Fuel. An estimated 82,000 Btu per gallon heat is required in an 800 HP coal (or combination coal, wood or natural gas) fired boiler. Such a boiler will require $.0023 worth of fuel per 1,000 Btu, assuming an 80 percent efficiency and using 11,000 Btu coal delivered at the site for $40.00 per ton. This fuel cost is $.19 per gallon of ethanol produced. The heat required has been derived from these calculations:

Operation	000 Btu/gal 200 proof
Cooking	3.6
Distillation	28.0
Dehydration	20.0
Drying	21.0
Miscellaneous	9.4
Total	82.0

Electricity. The electrical energy needed to operate the grinder, augers, mixers and pumps for this plant is estimated at .5 kWh per gallon. The assumed electrical rate per kWh is $.05 or rounded to $.03 per gallon.

Supplies. The alpha-amylase enzyme used in cooking starch is priced at $1.75 per lb at current commercial rates which amounts to $.03 lbs per bushel or $.0595 per bushel of corn. The glucoamylase enzyme used to convert starch to sugar is valued at $.08925 per bushel based on commercial price of $2.63 per liter. Dry, powdered yeast for the fermentation process is priced at $.84 per lb or $.05 per bushel of corn. These supplies total $.20 per bushel of corn and, with an estimated yield of 2.5 gallons per bushel, the per gallon cost is $.08. An additional .01 per gallon cost of acid, base and other chemicals make the total supply cost .09 per gallon.

b. Indirect costs

Indirect costs are annual costs and are independent of the number of gallons of ethanol produced. These are maintenance, general and administrative expense, property taxes, insurance, tax bond, and depreciation costs.

Maintenance. The annual cost for maintenance has been estimated to be 3 percent of the equipment investment cost for the first five years and 5 percent thereafter.

General and Administration. The estimated cost for management and marketing for this plant (general and administration) is based on a cost of two full-time persons with an annual cost of $50,000 per year total or $.03 per gallon.

Insurance. Four types of insurance are needed. Insurance rates vary from insurance company to company and state by state; however, for estimation purposes, rates quoted for a Midwestern location have been used for the following calculations:

Insurance Type	Rate	Annual premium
General liability		
$500,000 coverage	$.65/$100 payroll	$ 538
Product liability	$1.00/$100 sales	3,480
Workmen's compensation	$4.93/$100 payroll	4,930
Fire and extended coverage	$.80/$100 valuation	22,000
Total annual premium		$30,948

$30,948/2,000,000 gallons = $.01 per gallon

Taxes. Although taxes will vary by county and by state, two simplifying assumptions have been made for this report in order to estimate the tax cost. First, it has been assumed that tax valuation will be based on 20 percent of fair market value of the equipment investment cost. Second, the tax will be 100 mills on each dollar of valuation. For this model plant, the tax valuation will be $550,000 and the tax $55,000 per year or $.03 per gallon of ethanol.

Tax bond. According to current regulations, a holder of a BATF commercial permit must post a bond equivalent to the tax of $10.50 per proof gallon (100 proof) on 15 days alcohol production. For this plant, 15 days production in proof gallons is over the maximum tax liability of $200,000. Therefore, the cost of a tax bond for 200,000 is $2,400 per year based on a premium of $12.00/$1,000 bond or $.001/gallon of production.

Depreciation. The calculation of this cost is important only for income tax calculation. From preceding financial analyses sections, depreciation is shown as a part of the capital recovery. However, the expected life of the equipment is a key determinant in calculating depreciation and capital recovery. For the plant shown in this model size, 20 years has been assumed to be the life of the plant, a period which makes the depreciation rate 5 percent. With the investment cost of $2,750,000, the depreciation is $137,500 annually or $.07 per gallon.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gallon)
Direct		
Labor	84.0	.04
Fuel	380.0	.19
Electricity	50.0	.03
Supplies	180.0	.09
Total	694.0	.35
Indirect		
Maintenance	74.3	.04
General and administrative	50.0	.03
Taxes	55.0	.03
Insurance	30.9	.01
Tax bond	2.4	.00
Total	212.6	.11

G. Model Central Dehydration Plant

A variation of the model plants previously described will be the operation of a centralized dehydration process. This alternative model plant will operate a collection service and process lower proof ethanol, produced elsewhere into anhydrous or 200 proof ethanol.

This plant will operate as an addition to a community plant which produces its own anhydrous product via fermentation and, in addition, has extra dehydration capacity. Such a plant will probably not operate as a stand-alone plant because of the economies possible when it is attached to an ethanol production plant. If designed originally with oversized dehydration capacities, the equipment will be sized accordingly. However, for purposes of this analysis, it is assumed that the dehydration equipment is duplicated and operated as one unit.

1. Type and Size of Operation

This plant will be designed as an addition to the small community model plants and will produce 1 million gallons of anhydrous ethanol annually with dehydration equipment capacity to process an additional 1 million gallons of 190 proof ethanol. The additional dehydration unit will operate 300 days per year at the rate of 150 gallons per hour.

2. Location

The plant will be located as an integral part of the small community model plants.

3. Feedstock

The feedstock for the plant will be 190 proof ethanol collected by tank truck from a variety of on-farm ethanol plants within an average 10 mile radius of the central plant.

4. Type and Use of Product

The final and only product will be 200 proof ethanol. This will be combined with the 200 proof ethanol produced at the plant and marketed through its distribution system.

5. Investment Cost

The following equipment list represents the additional equipment to dehydrate the additional ethanol. The equipment for producing the 190 proof feedstock has already been described in models for the on-farm model plants.

Item	Cost $000
2,500 gallon tank truck	45
25,000 gallon storage tank	10
Unloading and metering equipment	2
Dehydration column 24" x 30" plates	25
Condenser/heater	3
Product cooler	4
Benzene cooler	2
Benzene column calandria	5
Instrumentation	10
Ethanol storage tank 25,000 gallons	10
Additional 100 horsepower boiler	36
Subtotal	152
Engineering and installation	50
Total investment cost	202

Additional working capital to finance 15 day feedstock operating costs, and final product $150,000

6. Operating Costs

The operating costs for this plant are the direct costs associated with the number of gallons of product processed and the indirect costs, normally annual costs not related directly to production.

a. Direct Costs

The direct costs are the costs of collecting lower proof ethanol from the farm, transporting the product to the central plant, and dehydrating it. They include labor, fuel, electricity, supplies and trucking costs.

Labor. One man with a truck can transport 2,500 gallons of 190 proof from the farm to the central plant, can run 2 trips per day, and load and unload the product while working an eight hour day, 5 day week. An assumed rate of $6.00 per hour computes to $48 per day, $240 per week or $12,500 per year. Based on 1 million annual gallons, the per gallon cost is $.01.

Fuel. The estimated energy requirements for the dehydration process is 20,000 Btu per gallon. Assuming a coal fired boiler using $40 per ton coal (80 percent efficiency), the fuel cost per gallon is $.043 rounded to $.05.

Electricity. The electrical power estimate is less than 0.2 kWh per gallon for the pumping requirements on a per gallon basis. Assuming electrical costs at $.05/kWh, the electrical cost is $.01/gallon.

Truck costs. The truck costs are based on the operation of a single truck that will make 2 trips per day, hauling 2,500 gallons per trip, for a five-day week, 43 week year. This schedule will meet the requirements of the

plant. The collection area is estimated to lie within a 10-mile radius with the average trip length out and back of 20 miles. Thus the annual mileage is 8,600 miles with an assumed per mile cost of $1.00. Adjusting the annual cost of $8,600 to a per gallon cost, results in $.0086 per gallon or $.01.

b. Indirect Costs

Maintenance. Costs for maintenance have been estimated at 3 percent of the equipment cost for the first 5 years and 5 percent for the remaining 15 years of plant life.

General and Administration. To coordinate and schedule the pickup of lower proof ethanol and to keep records of all the transactions of the collection system, one person has been designated as the administrator. The annual cost is $15,000 which rounds to $.02 per gallon for this general and administration cost.

Insurance and Taxes. The property tax cost for the additional property valuation for this plant is based on 20 percent of the $202,000 investment cost of the equipment times the tax rate of 100 mills or a $4,500 per year tax cost. The tax bond cost will require another tax bond to cover transportation functions and will be $2,400 per year. The insurance cost is as follows:

Insurance Type and Rate	Annual Premium
General liability $.65/$100 payroll	179
Product liability $1.00/$1000 sales	1,500
Workmens Compensation $4.93/$100 payroll	616
Fire and extended coverage $.80/$1,000	1,616
Total	$3,911

These annual costs total $10,811 or $.01 per gallon of ethanol processed.

Depreciation. Depreciation as shown here is a memo cost only as it appears as part of the capital recovery in the financial analysis. For purposes of this display, depreciation is 5 percent per year $10,100 or $.01 per gallon.

c. Summary of conversion costs

Item	Annual ($000)	Unit ($/gal)
Direct		
Labor	12.5	.01
Fuel	46.3	.05
Electricity	10.0	.01
Truck costs	8.6	.01
Total	77.4	.08
Indirect		
Maintenance	6.0	.01
General and Administrative	15.0	.02
Taxes and insurance	10.8	.01
Total	31.8	.04

APPENDIX B

GUIDELINES FOR ASSESSMENT OF PLANT DESIGN

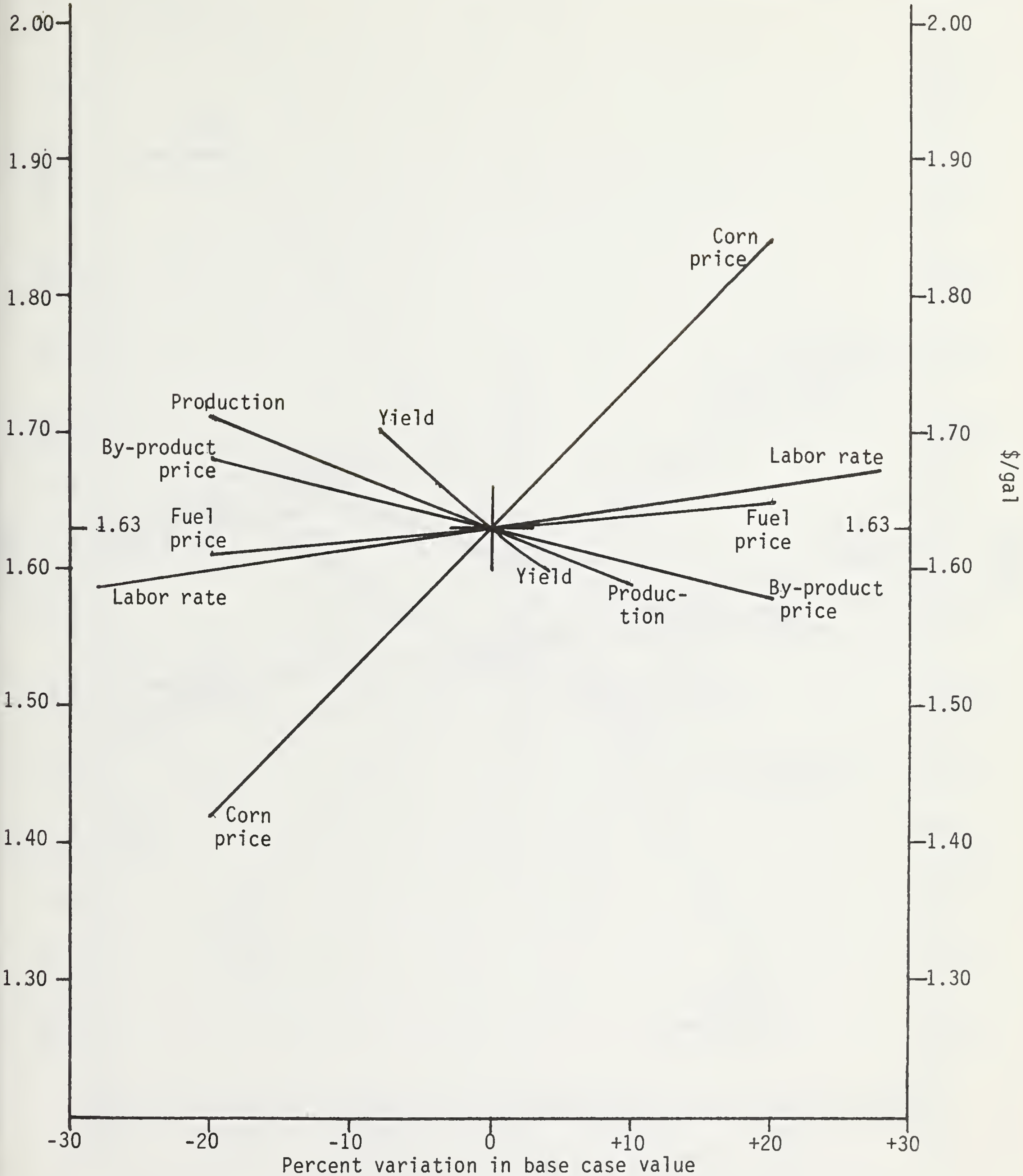


Figure B-1. Annual operating variables--Pot Still

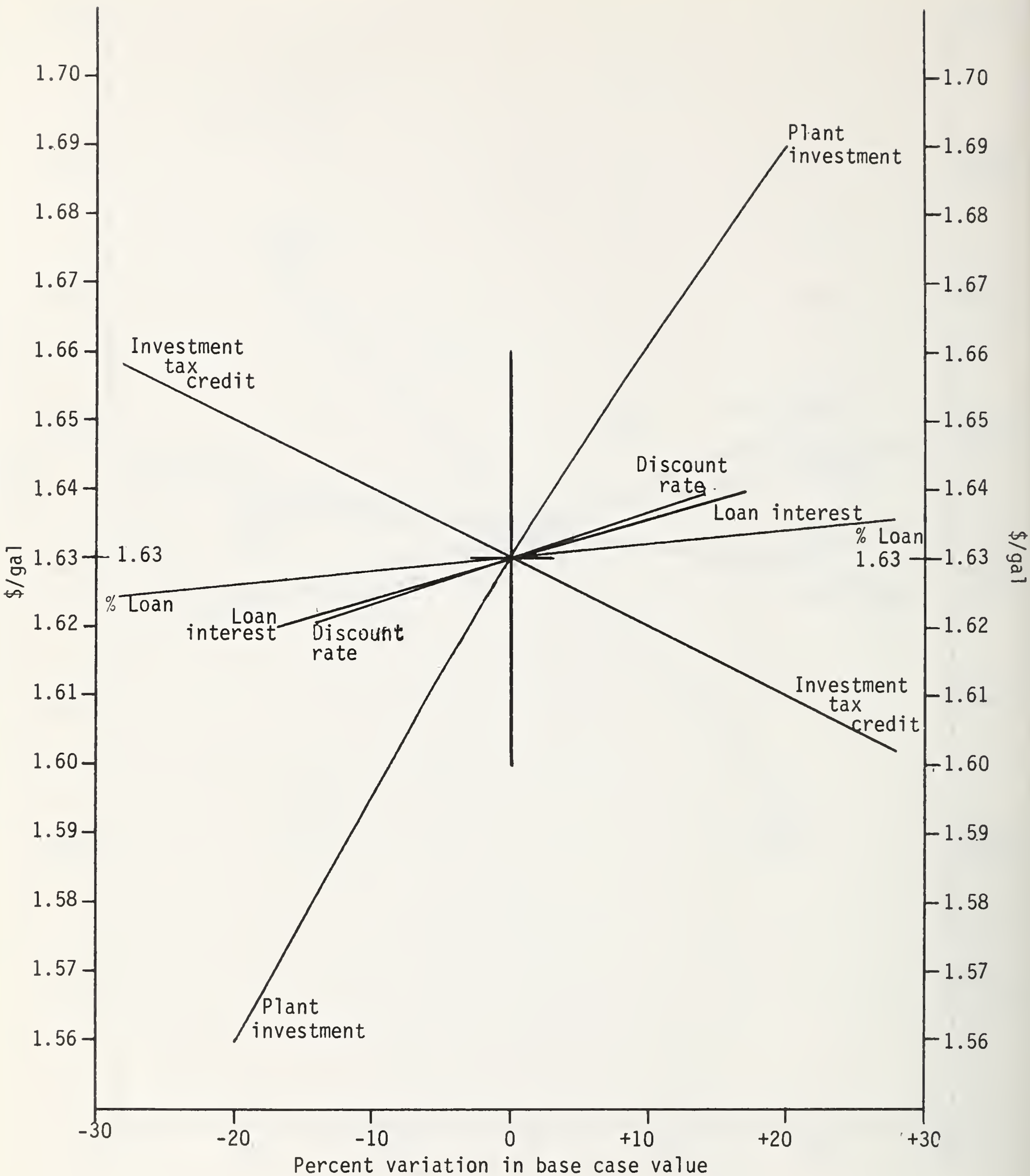


Figure B-2. Equivalent capital cost--Pot still

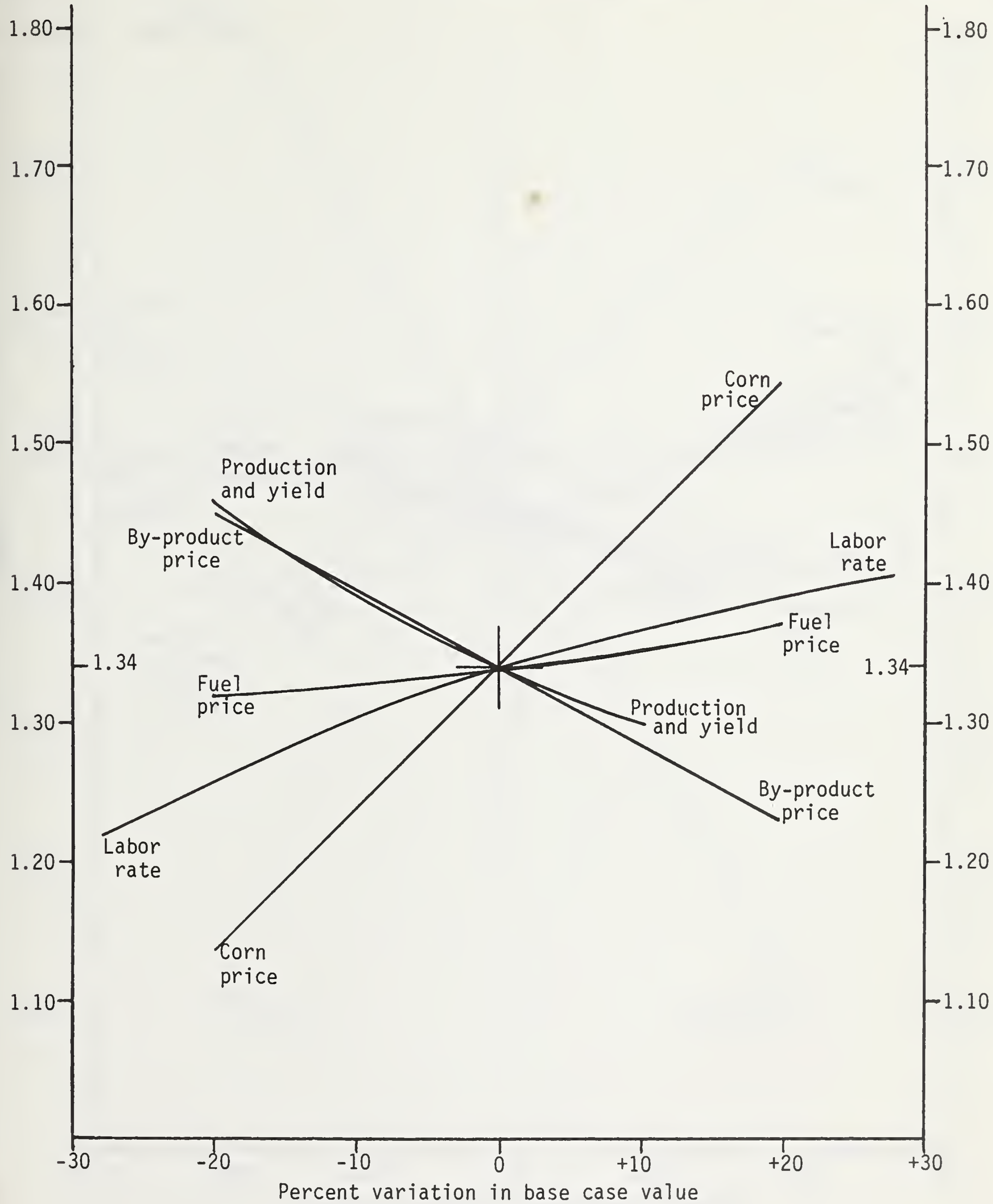


Figure B-3. Annual operating variables--Small on-farm

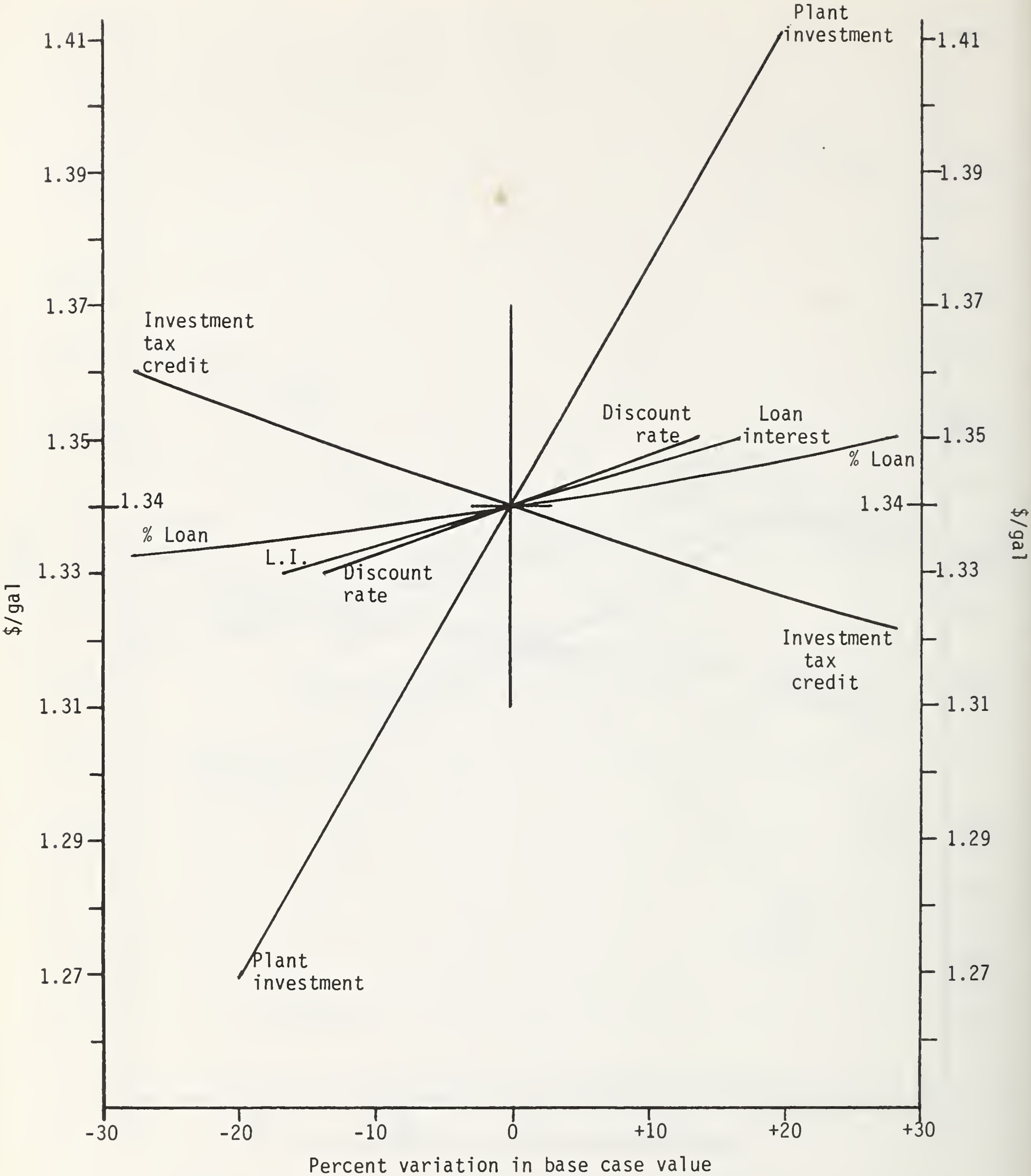


Figure B-4. Equivalent capital cost--Small on-farm

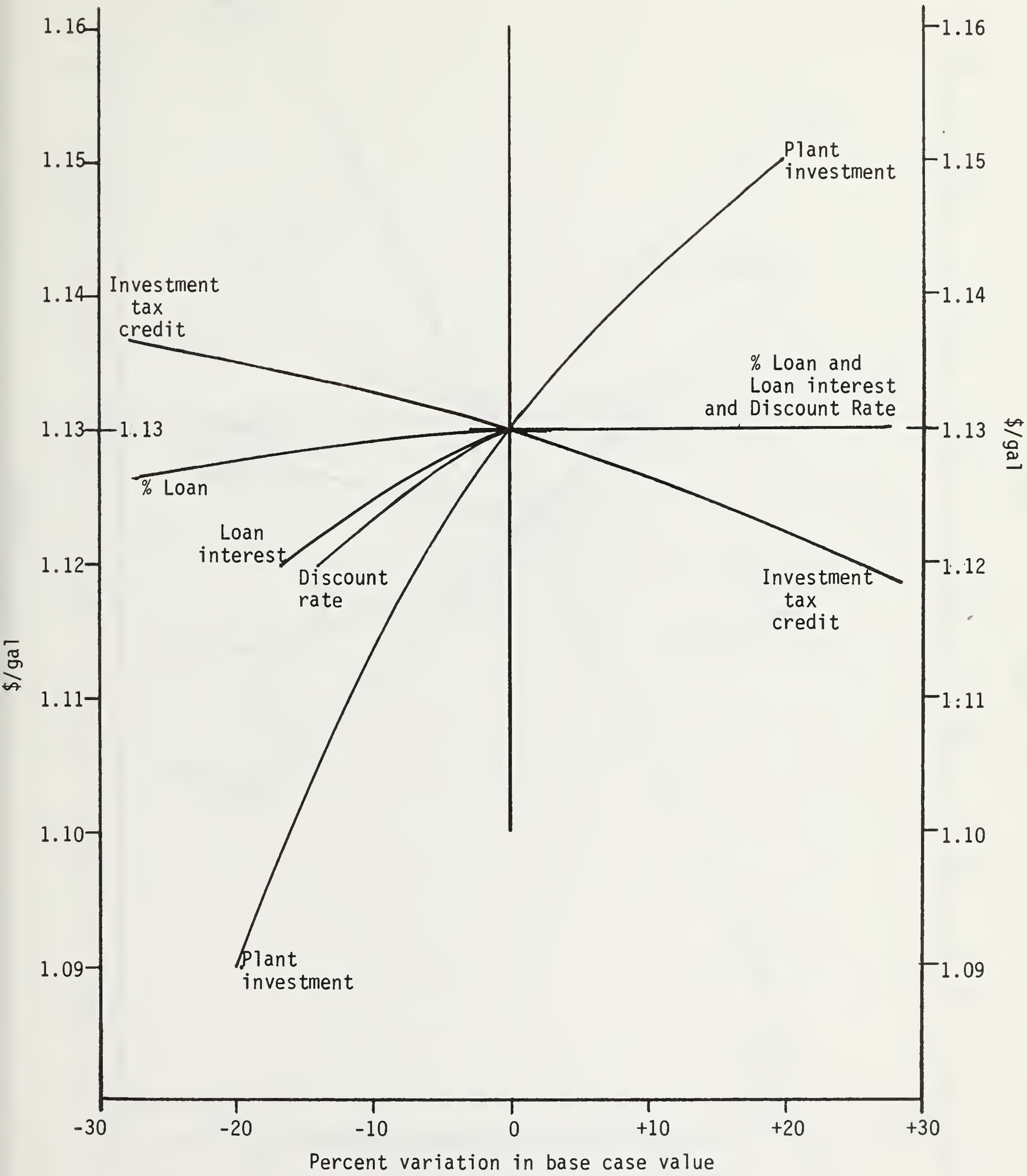


Figure B-5. Annual operating variables--Large on-farm

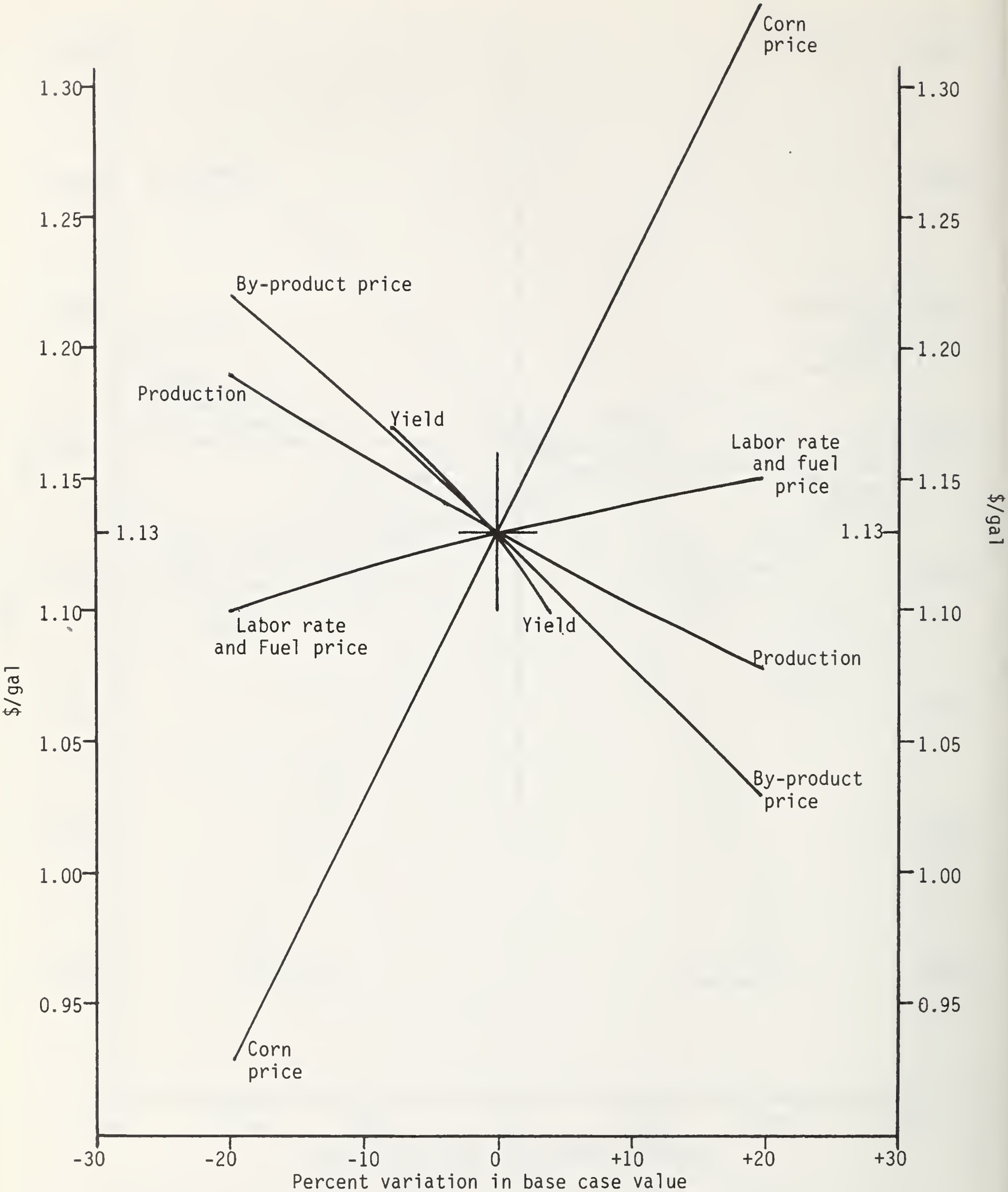


Figure B-6. Equivalent capital cost--Large on-farm

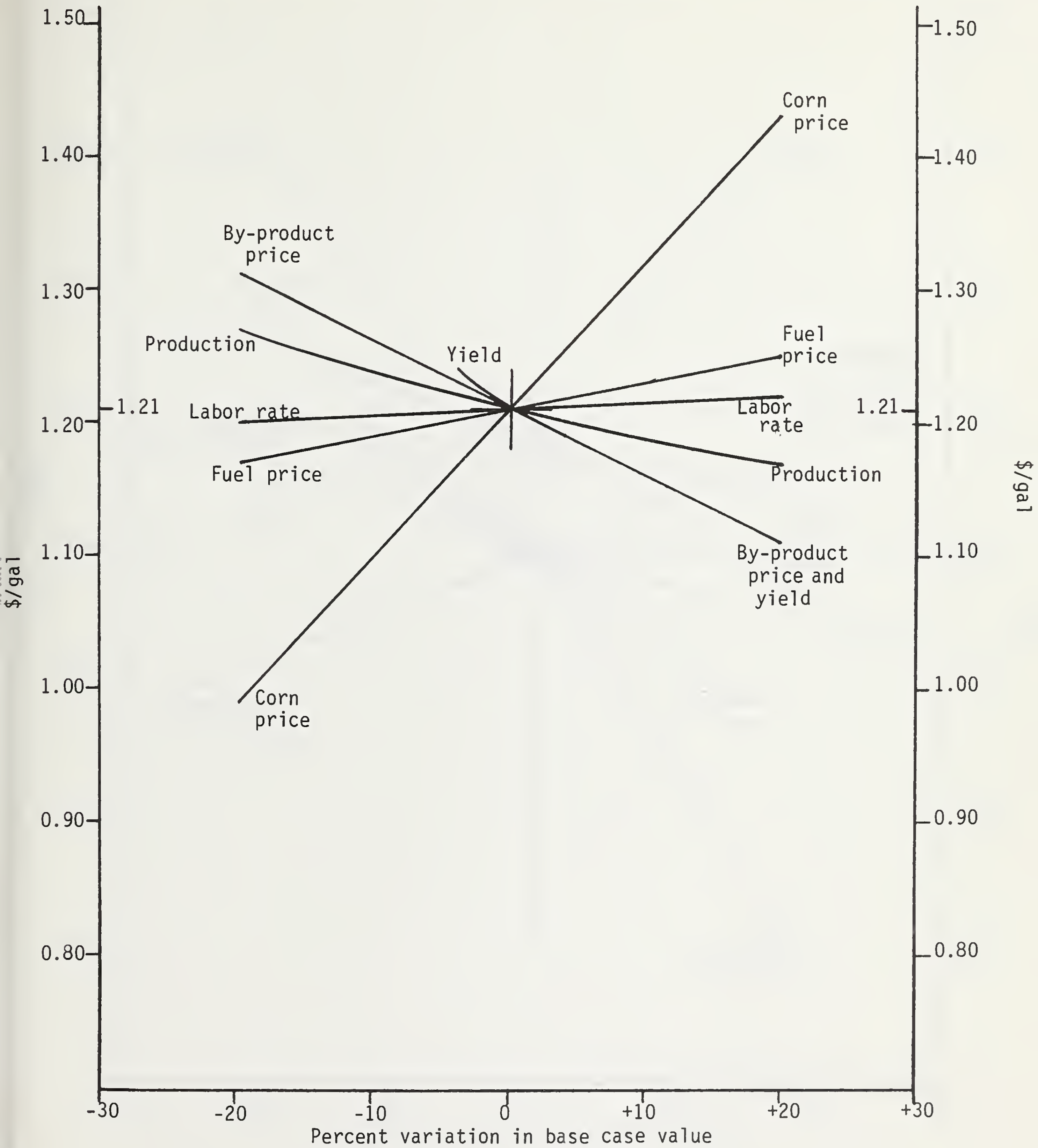


Figure B-7. Annual operating variables--Small community, wet

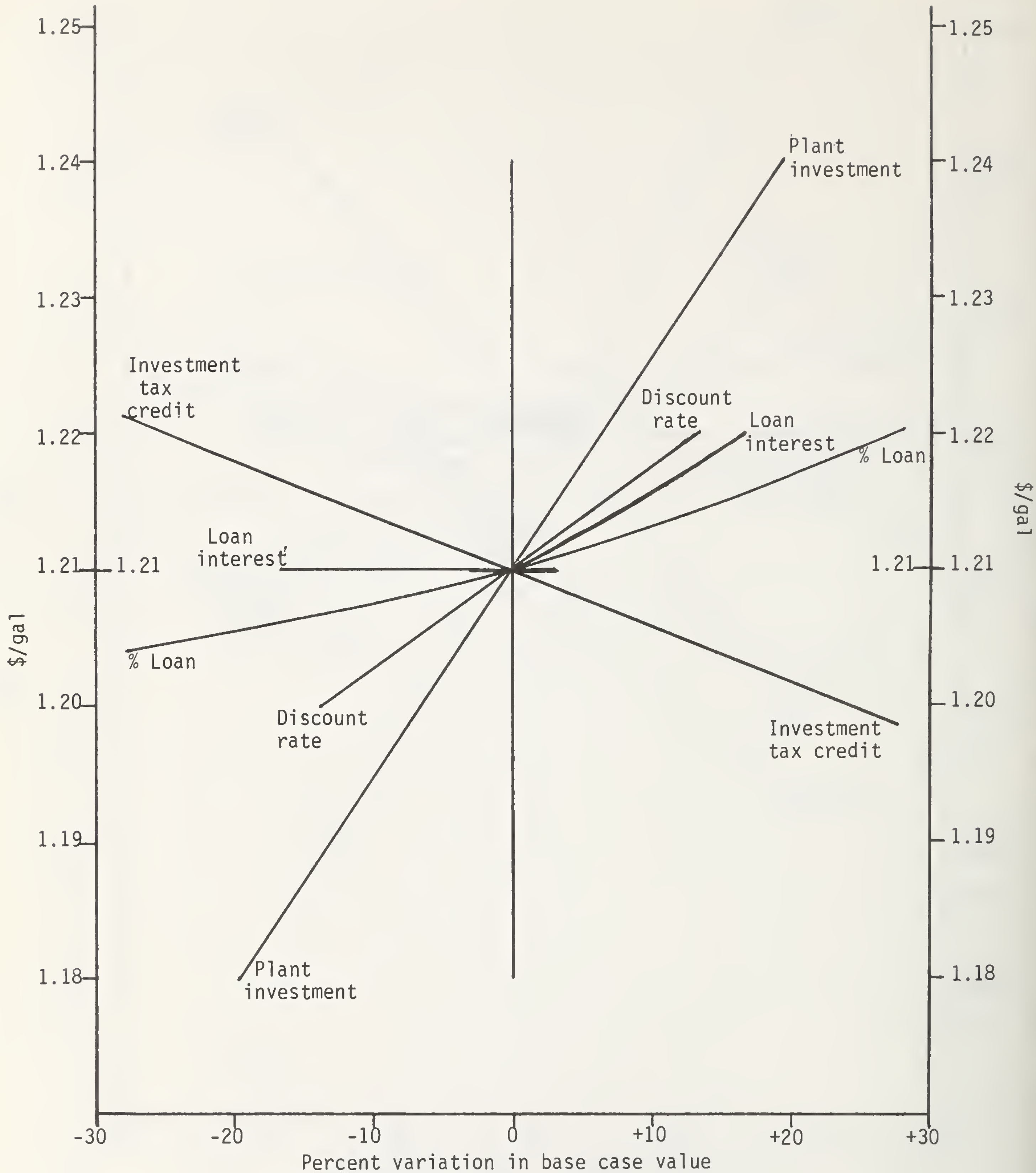


Figure B-8. Equivalent capital cost--Small community, wet

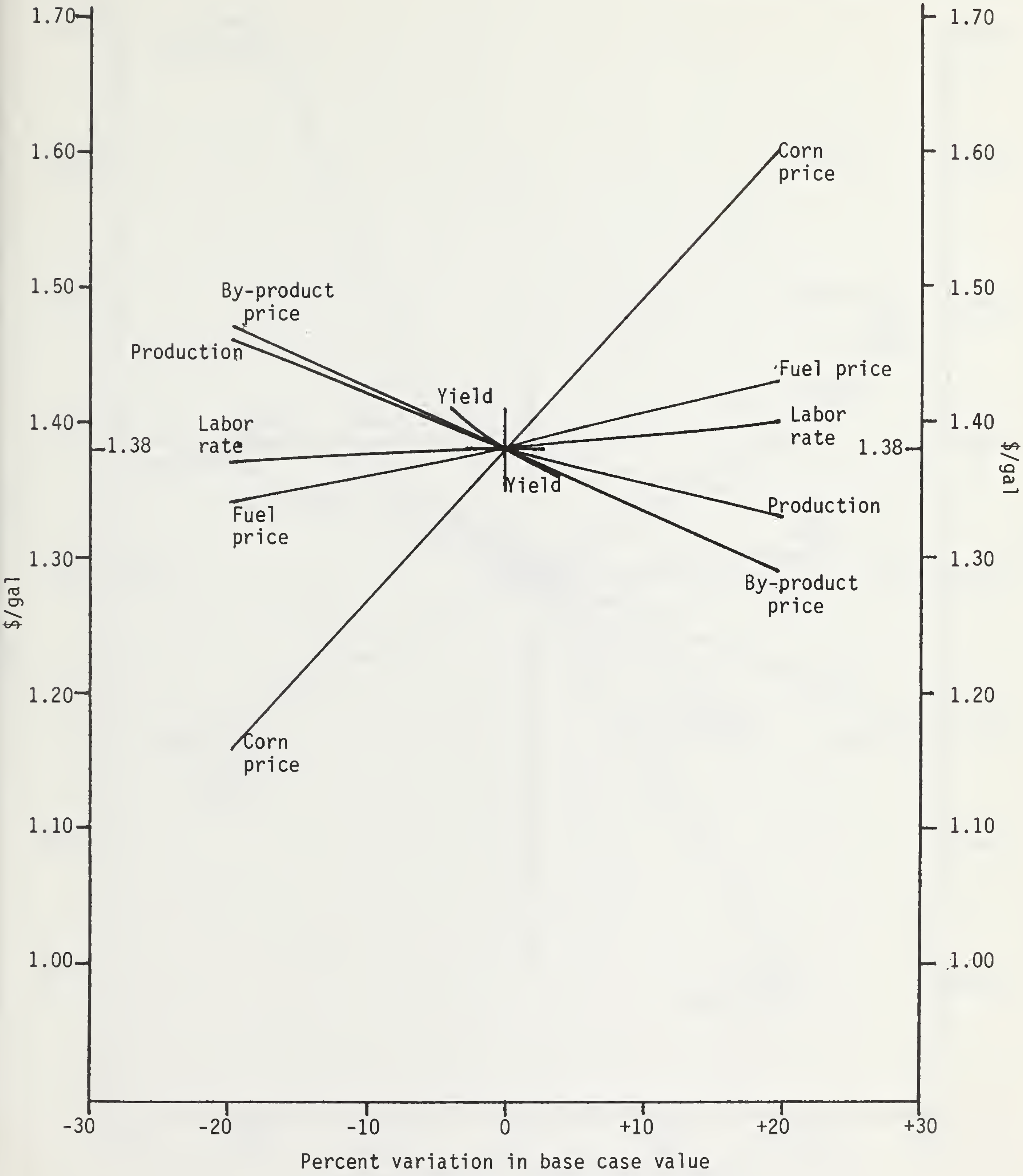


Figure B-9. Annual operating variables--Small-community, DDGS

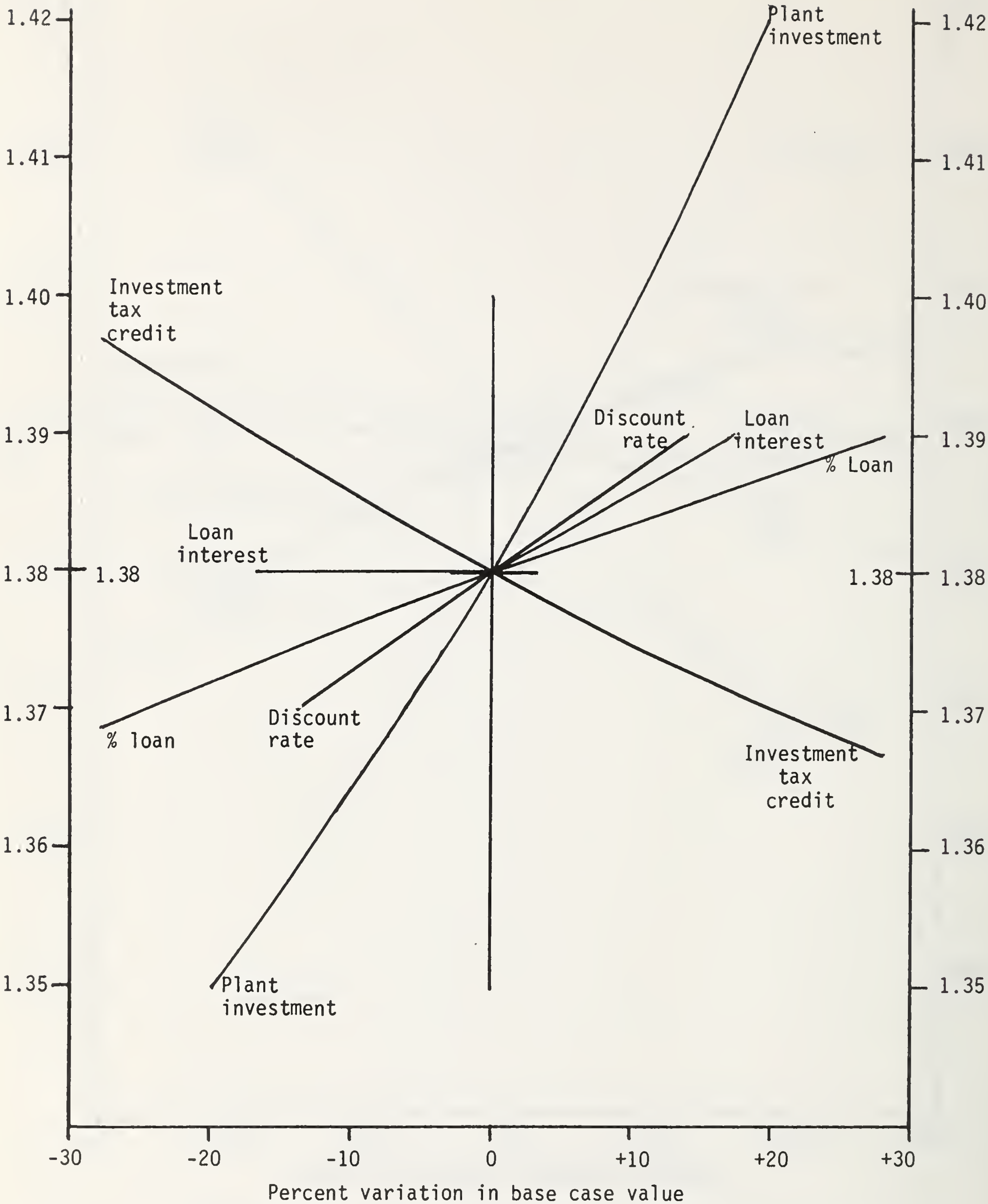


Figure B-10. Equivalent capital cost--Small community, DDGS

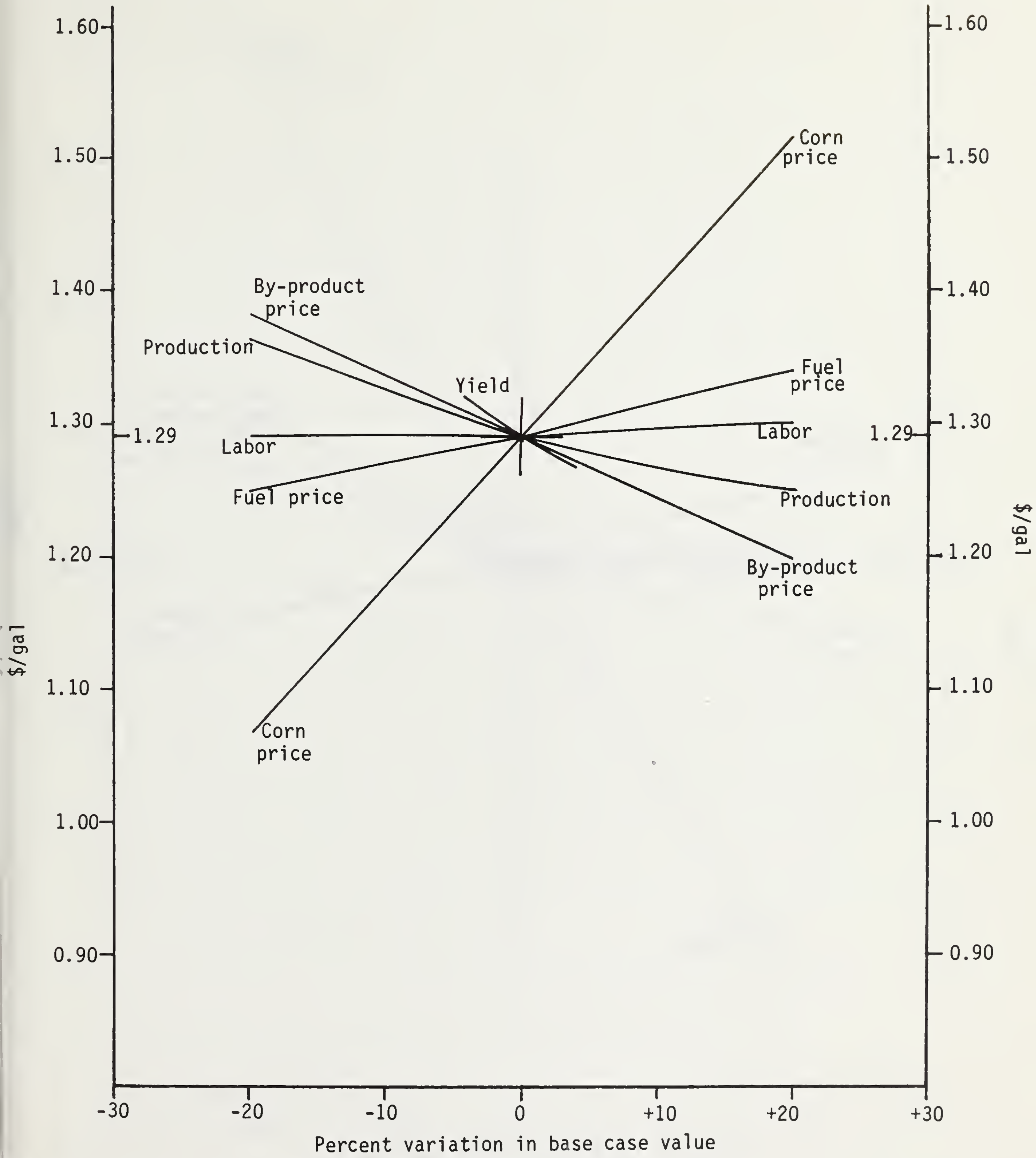


Figure B-11. Annual operating variables--Large community, DDGS

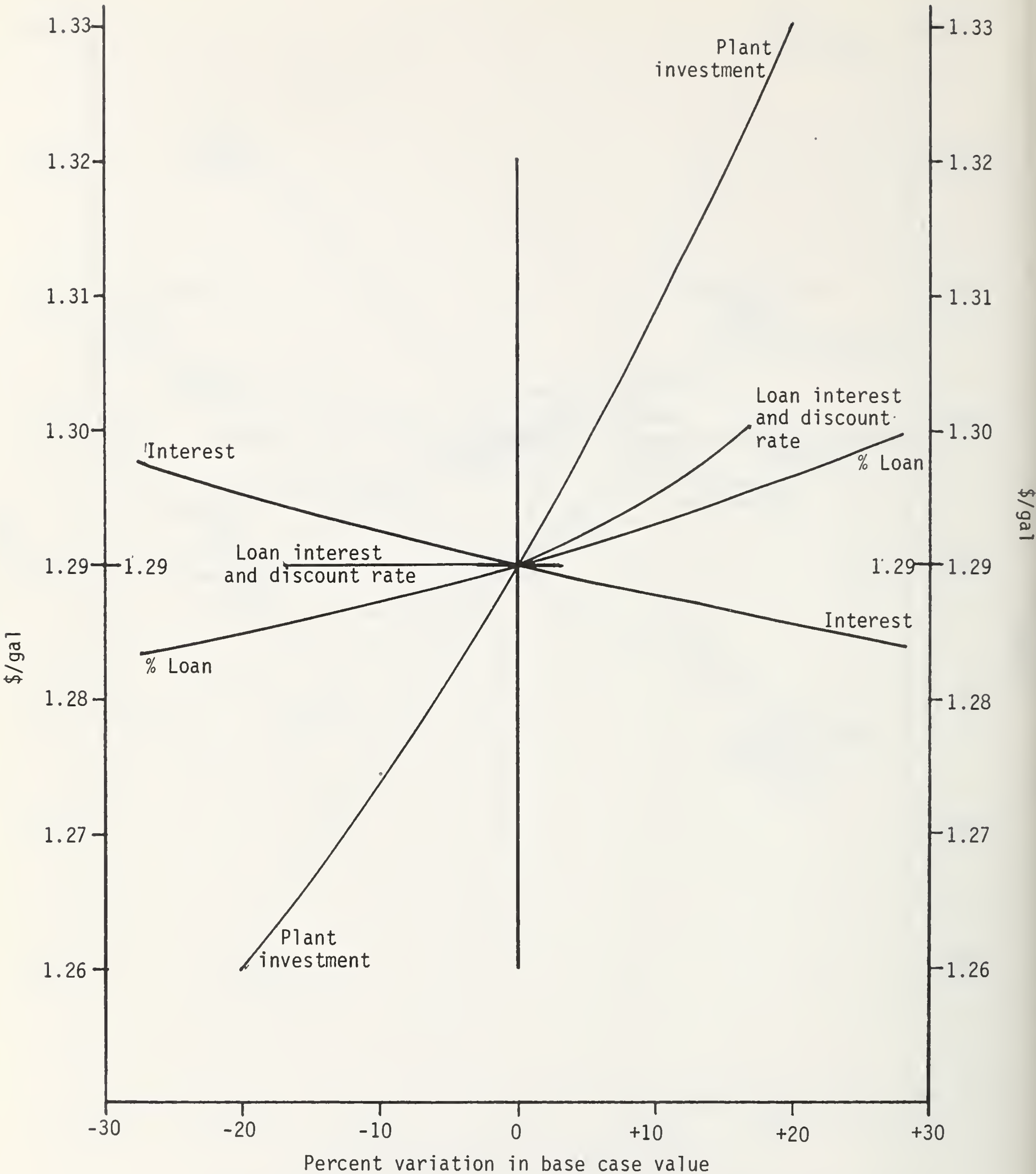


Figure B-12. Equivalent capital cost--Large community, DDGS

APPENDIX C

REFERENCES

CHAPTER II

References

1. Keller, J.L., et.al., Use of Alcohol in Motor Gasoline--A Review, American Petroleum Institute, August, 1971.

2. Lichty, L.C., Combustion Engines Processes, McGraw-Hill, 1967.

3. Taylor and Taylor, The Internal Combustion Engine, International Textbook Company, 2nd Ed., 1966.

4. Keller, J.L., Methanol and Ethanol Fuels for Modern Cars, Union Oil Company, presentation for World Federation of Engineering Organizations, November 1979.

5. The U.S. Food and Fiber Sector: Energy Use and Outlook, U.S. Department of Agriculture, Economic Research Service, Senate Committee on Agriculture and Forestry, 1974.

6. Yahya and Goering, Some Trends in Fifty-five Years of Nebraska Tractor Tests, University of Missouri, ASAE paper no. MC-77-503.

7. Schrock, M.D., Clark, S.J., Kramer, J.A., Fuel Requirements for Field Operations in Kansas, Extension Bulletin to be published 1980.

8. Lucke, C.E., "The Use of Alcohol and Gasoline in Farm Engines" Farmers Bulletin No. 277, USDA, February 17, 1907.

9. Woods, D., Private Communication, December, 1979.

10. Schroder, E., Private Communication, October, 1979.

11. Lichty, L.C., and Phelps, C.W., Gasoline-Alcohol Blends in Internal Combustion Engines, Industrial and Engineering Chemistry, Vol. 30, No. 1, February 1938.

12. Brinkman, N.D., Gallopoulos, N.E., Jackson, M.W., Exhaust Emissions, Fuel Economy, and Driveability of Vehicles Fueled with Alcohol-Gasoline Blends, SAE paper 750120, February, 1975.

13. Scheller, W.A., The Use of Ethanol-Gasoline Mixtures for Automotive Fuel, Univ. of Nebraska, Lincoln, January, 1977.

14. Barger, E.L., Power Alcohol in Tractors and Farm Engines, Agricultural Engineering, February 1941.

15. Freeman, J. H., et al., Alcohols - A Technical Assessment of Their Application as Fuels, American Petroleum Institute, July, 1976.

16. Courtney, R.L. and Newhall, H.K., A Primer on Current Automotive Fuels, Automotive Engineering, December 1979.

17. Anon, Engineering Highlights of the 1980 Automobiles, Automotive Engineering, November 1979.

18. Sheller, W.A., Tests on Unleaded Gasoline Containing 10% Ethanol--Nebraska Gasohol, International Symposium on Alcohol Fuel Technology Methanol and Ethanol, November 21-23, 1977, Wolfsburg, Germany.

19. Mueller Assoc., Status of Alcohol Fuels Utilization Technology for Highway Transportation, U.S. Dept. of Energy, June 1978.

20. Pefley, R.K., Alcohol Fueled Automobiles Performance--Emissions--Environment, University of Santa Clara, October 1979.

21. Anon, Gasohol and Diesohol Tested in Farm Tractors, Doanes Agricultural Report, Vol. 42, No. 42-5, October 1979.

22. Obert, E.F., Internal Combustion Engines, International Textbook Company, December 1968.

23. Bandel, W., Problems in the Application of Ethanol As a Fuel for Utility Vehicles, International Symposium on Alcohol Fuel Technology Methanol and Ethanol, November 21-23, 1977, Wolfsburg, Germany.

24. Bernhardt, W., Possibilities for Cost Effective Use of Alcohol Fuels in Otto Engine-Powered Vehicles, International Symposium on Alcohol Fuel Technology Methanol and Ethanol, November 21-23, 1977, Wolfsburg, Germany.

25. Ethanol Production and Utilization for Fuel, Cooperative Extension Service University of Nebraska, Lincoln, 1979.

26. Anon, "Spectrum," Grounds Maintenance, July 1979.

27. Owens E.C., "Effects of Alcohol-Containing Fuels on Spark Ignition Engine Wear," U.S. Army FUels and Lubricants Research Laboratory, Southwest Research Institute, April 1979.

28. Scheller, W.A., and Mohr, B.J., Gasohol Road Test Program Second Progress Report, Univ. of Nebraska, Lincoln, July, 1975.

29. Wiebe, R. and Hummell, J.D., "Practical Experiences with Alcohol-Water Injection in Trucks and Farm Tractors," Agricultural Engineering, May 1954.

30. Allsup, J.R. and Eccleston, D.B., "Ethanol-Gasoline Blends as Automotive Fuel," Bartlesville Energy Technology Center, 1979.

31. Duck, J.T., and Bruce, C.S., "Utilization of Non Petroleum Fuels In Automotive Engines," Natl Bur. Std., J. Res. 35:439 (1945)

32. Meyer A.J. and Davis R.E., "Burning Alcohol in a Gasoline Tractor and Thermodynamic Properties of an Ethyl Alcohol-Air Mixture and Its Products," Univ. Kentucky Engg Exp Sta Bull, 2:4 (1948)

33. Kirik, M., "Alcohol as Motor Fuel," Ontario Ministry of Agriculture and Food, 1979.

34. Cummings D.R. and Scott, W.M., "Dual Fuelling the Truck Diesel with Methanol," International SYmposium on Alcohol Fuel Technology Methanol and Ethanol, Nov. 21-23, 1977, Wolfsburg, Germany.

35. Strait, J. Boedicker, J.J. and Johansen, K.C., Diesel Oil and Ethanol Mixtures for Diesel Powered Farm Tractors, Univ. of Minn., 1978.

36. Wrage, K.E., and Goering, C.E., "Technical Feasibility of Diesohol," Agricultural Engineering, October 1979.

37. Meiners, E., "M&W Water/Alcohol Injection in Diesel Engines," M&W Gear, August 1979.

38. Panchapakesan, N.R., Gopalakrishnan, K.V., and Murthy, B.S., "Factors that Improve the Performance of an Ethanol-Diesel Oil Dual-Fuel Engine," International SYmposium on Alcohol Fuel Technology Methanol and Ethanol, November 21-23, 1977, Wolfsburg, Germany.

39. Bro., K., and Pedersen, P.S., "Alternative Diesel Engine Fuels: An Experimental Investigation of Methanol, Ethanol, Methane, and Ammonia in a D.I. Diesel Engine with Pilot Injection," SAE paper 770794, 1977.

40. Barnes, K.D., Kittelson, D.B., and Murphy, T.E., "Effect of Alcohol as Supplemental FUel for Turbocharged Diesel Engines," SAE paper 750469, 1975.

41. Leviticus, L.E., "Nebraska Tractor Test Data, 1979" University of Nebraska, Tractor Testing Lab.

42. Bailey, B.K., and Russel, J.A., Emergency Fuels Composition and Impact, Phase II Formulation and Screening Diesel Emergency Fuels, MED Report 101, Southwest Research Institute, June 1979.

43. Private Communication, Cummins Rio Grande, January, 1980.

44. Kaufman, K. R. and Klosterman, H. J., "A Highway Test of Gasohol", Farm Research, Vol. 37, No. 1, July-August, 1979.

45. Mingle, J. G., "Converting Your Car to Run on Alcohol Fuels", Bulletin 56, Oregon State University Experiment Station, October, 1979.

46. U.S. Department of Agriculture, Changes in Farm Production and Efficiency, 1978, Economics, Statistics and Cooperative Service, Statistical Bulletin No. 628, January 1980.

CHAPTER III

References

1. Summary of Illinois Farm Business Records, 1978, University of Illinois.

2. Southeastern Minnesota Farm Management Association, 1978 Report, University of Minnesota.

3. Farm Management Summary and Analysis, 1978, Kansas State University.

4. U.S. Department of Agriculture, Agricultural Statistics, 1978.

5. U.S. Department of Agriculture/Federal Energy Administration, Energy and Agriculture, 1974 Data Base, 1972.

6. U.S. Department of Energy, Energy Information Administration, Monthly Energy Review, September 1979.

7. U.S. Department of Agriculture, Economics, Statistics, and Cooperative Service, "Costs of Producing Selected Crops in the United States--1977, 1978 and Projection for 1979 for the Committee on Agriculture, Nutrition and Forestry, United States Senate, June 15, 1979.

8. U.S. Department of Agriculture: Energy In Agriculture, 1978 (unpublished data).

CHAPTER IV

References

1. Shelton, D. and A.R. Rider,"Ethanol Production Equipment and Processes," Ethanol Production and Utilization for Fuel, Cooperative Extension Service, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, October, 1979.

2. Crombie, Lance, Making Alcohol Fuel, Recipe and Procedure, Rutan Publishing, Minneapolis, 1979.

3. Wachler, James P., Miles Laboratory, Elkhart, Indiana, personal communication, November 1979.

4. Alfa-Laval, Fermenter Cooling System for Alcohol Fermentations, NOTB40536E 3 undated.

5. Universal Foods Corporation, Fermentation Alcohol for use in "gasohol," Milwaukee, Wisconsin, 1979.

6. Underkoffer, L.A. and R.J. Hickey (eds.) Industrial Fermentation, Chemical Publishing Co. Inc., N.Y., 1954, Vol. I.

7. Heinz, Don J., Technology of Ethanol Production Hawaiian Sugar Planters' Association, Media Briefing on Energy, September 11, 1979.

8. Shreve, R. Norris, Ed., Chemical Process Industries, McGraw-Hill Book Company, N.Y., 1967.

9. Department of the Treasury, Bureau of Alcohol, Tobacco and Firearms, "Ethyl Alcohol for Fuel Use," ATFP 5000, 1 (9-78), Available from U.S. Government Printing Office Stock Number 048-012-00045-1.

CHAPTER V

References

1. Morrison, Frank B., Feeds and Feeding, Abridged, Ninth edition, The Morrison Publishing Co., 1961.

2. United States Department of Agriculture, Agricultural Statistics, U.S. Government Printing Office, Washington, 1977 and 1978.

3. United States Department of Agriculture, Motor Fuels from Farm Products, Miscellaneous Publication No. 327, Washington, D.C., December 1938.

4. Federal Energy Administration and U.S. Department of Administration, Energy and U.S. Agriculture: 1974 Data Base, Vol. 2: Commody Series of Energy Tables, 1977.

5. Nathan, Richard A., Fuels from Sugar Cane: Systems Study for Sugarcane, Sweet Sorghum and Sugar Beets, Technical Information Center, U.S. Department of Energy, 1978.

6. Lipinski, E.S., D.R. Jackson, S. Kresovich, M.F. Arthur, and W.T. Lawkon, "Carbohydrate Crops as a Renewable Resource for Fuel Production," Vol. I: Agricultural Research, Battelle Columbus Division, May 15, 1979.

7. Lipinski, E.S., personal communication, October 1979.

8. U.S. Department of Agriculture: Energy in Agriculture, 1978 (unpublished data).

CHAPTER VI

References

1. Wilford, E.J., Distillery Slop for Hogs, Ky. Ag. Res. Bul. 408, 1944.

2. Garrigus, W.P., Wet Stillage for Beef Cattle, Distillers Feed Res. Corn. Proc. 3, 1948.

3. Leitch, I. and J.S. Thompson, The water economy of farm animals. Nutrition Abstracts and Reviews. 16:2, pp. 197-223, 1944.

4. Barber, R.S., R. Braude, and K.G. Mitchell. Further studies on the water requirements of the growing pig. An Prod. 5, pp. 277-282, 1963.

5. Holme, D.W. and K.L. Robinson. A study of water allowances for the bacon pig. An. Prod. 7, pp. 377-384, 1965.

6. Braude, R. and J.G. Rowell. Comparison of dry and wet feeding of growing pigs, J. Agric., Sci. Camb., 68, pp.325-330, 1967.

7. Gardner, F.H. and H.G. Sanders. The water consumption of suckling sows. J. Agric. Sci. 27, pp. 638-643, 1937.

8. Mount, L.E., C.W. Holmes, W.H. Close, S.R. Morrison, and I.B. Start. A note on the consumption of water by the growing pig at several environmental temperatures and levels of feeding. Anim. Prod. 13, pp. 561-563, 1971.

9. Winchester, C.F. and M.J. Morris, Water intake rates of cattle. J. Anim. Sci. 15, pp.722-740, 1956.

10. Ittner, N.R., C.F. Kelley, and N.R. Guilbert, Water consumption of Hereford and Braham cattle and the effect of cooled drinking water in a hot climate. J. Anim. Sci., 10, pp.742-751, 1962.

11. Brady, S., A.C. Ragsdale, H.J. Thompson, and D.M. Worstell. The effect of wind on milk production, feed and water consumption and body weight in dairy cattle. Res. Bul. 45, Univ. of Mo. Ag Expt. Sta., 1954.

12. Owen, J.B. E.L. Miller and P.S. Bridge. A study of the voluntary intake of food and water and the lactation performance of cows given diets of varying roughage content ad libitum. J. Agr. Sci. 70, pp.223-235, 1968.

13. Steckley, J.D., D.G. Grieve, G.K. MacLeod and E.T. Moran, Brewers Yeast Slurry, I. Composition as Affected by Length of Storage, Temperature and Chemical Treatment. J. Dairy Sci., 62:941-946, 1979.

14. Miller, T.B., Evaluation of Whiskey Distillery By-products, I. Chemical composition and losses during transport and storage of malt distillers grains. J. Sci. FD. Agric. 20:477-481, 1969.

15. Lipinsky, E.S., D.A. Scantland and T.A. McCLure. (1979) Systems Study of the Potential Integration of U.S. Corn Production and Cattle Feeding with Manufacture of Fuels via Fermentation. Battelle, Columbus, Ohio.

16. Keinholz, E.W. and D.L. Rossiter. (1979) Grain Alcohol Fermentation By-Products for Feeding in Colorado. Colo. State Univ., Ft Collins, CO.

CHAPTER VII

References

1. David, M.L., *et al.*, Gasohol: Economic Feasibility Study, U.S. Department of Energy, SAN 1681-T1, July 1978.

☆ U. S. GOVERNMENT PRINTING OFFICE : 1980 623-345/1397

U.S. DEPARTMENT OF AGRICULTURE
WASHINGTON, D C 20250

PENALTY FOR PRIVATE USE $300
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
U S DEPARTMENT OF
AGRICULTURE
AGR 101

U.S.MAIL